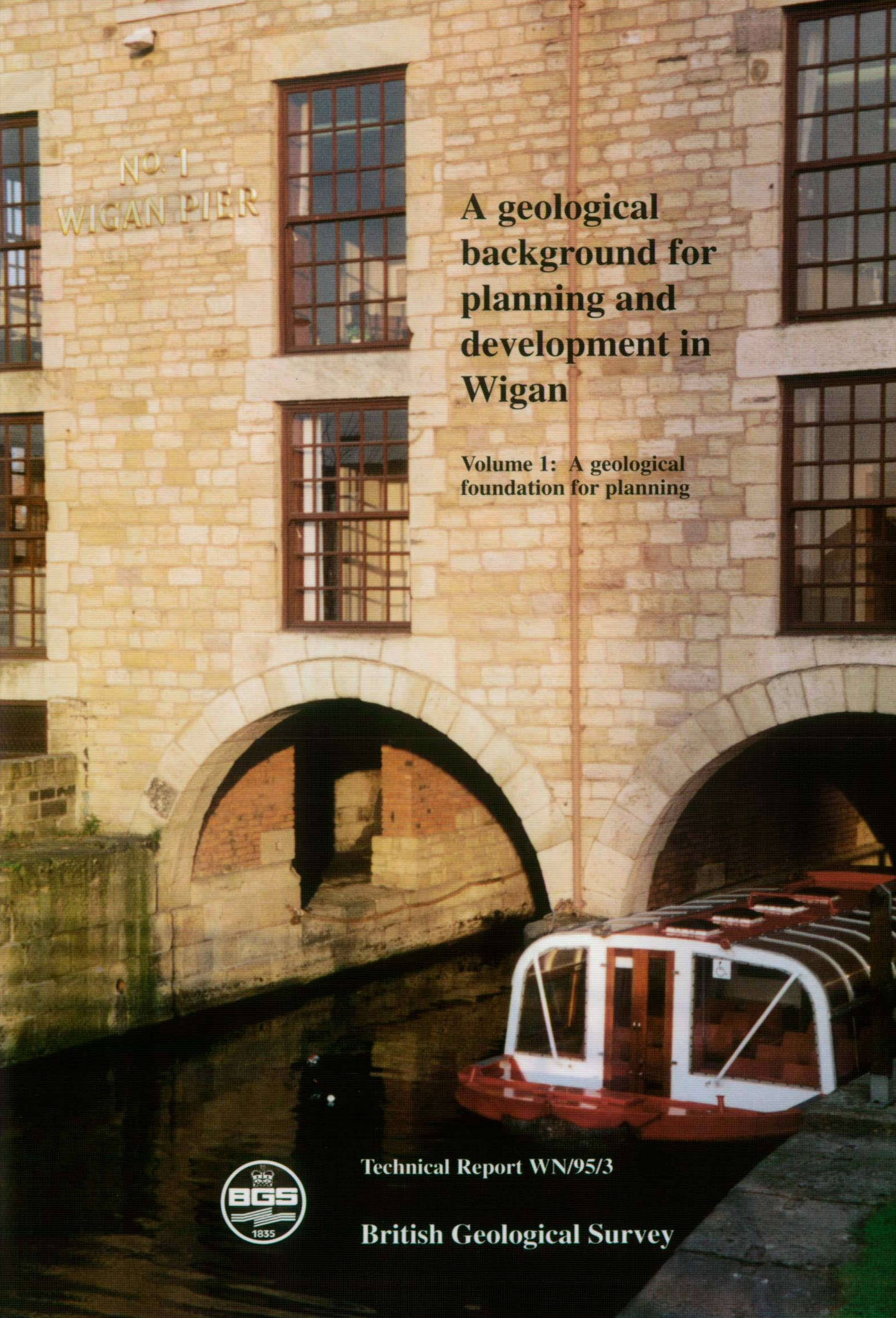

A geological background for planning and development in Wigan

Volume 1: A geological foundation for planning

Technical Report WN/95/3

British Geological Survey

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BRITISH GEOLOGICAL SURVEY
In association with
Roger Tym and Partners

TECHNICAL REPORT WN/95/3

A geological background for planning and development in Wigan

Volume 1: A geological foundation for planning

Editors: A Forster, A Arrick, M G Culshaw and M Johnston

Authors: A Forster, M Stewart, D J D Lawrence, A Arrick, C S Cheney, R S Ward, J D Appleton, D E Highley, A M MacDonald, and P D Roberts

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Maps and diagrams used in this report are based on Ordnance Survey mapping.

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1 Digest

This report, commissioned by the Department of the Environment, provides concise, accessible data on the geology of the Wigan Metropolitan Area and their implication for planning and development in the area. The report comprises two volumes:

- Volume 1: **'A Geological Foundation for Planning'**, concerns technical matters and describes the geological data collected.
- Volume 2: **'A user's guide to the Wigan's ground conditions'** applies the geological data to the workings of the local planning system and considers their implications for future planning and land use.

The study found that the geological factors perceived, by planners, developers and other interested parties, as being most relevant to planning and development in the area were:

- the presence of abandoned, shallow mineworkings;
- the potential for past or present industrial contamination of land;
- the potential for groundwater contamination;
- the presence of mineral resources;
- the presence of geological faults.

The report includes ten applied geological maps of the Wigan Metropolitan Area at a scale of 1:25 000 on the themes of:

- Distribution of pits, boreholes, and site investigations
- Bedrock geology
- Superficial geology
- Hydrogeology
- Mineral resources
- Distribution of made and worked ground
- Previous and present industrial use
- Engineering geology
- Shallow mining
- Geological factors relevant to land use planning

2 Executive summary

This volume is the first of a two volume report entitled **'A Geological Background for Planning and Development in Wigan'** that presents the results of a project commissioned by the Department of the Environment. The purpose of the project was to provide concise, accessible advice on the relevance of geological conditions in the Wigan area to land use planning and development and also to provide a regional context for site investigation. The project commenced in September 1992 and was completed in June 1995.

- Volume 1: **'A Geological Foundation for Planning'** is a technical report that describes the geological data collected, discusses the implications of the geological conditions for the area and presents the information in a comprehensive and structured format.
- Volume 2: **'A User's Guide to Wigan's Ground Conditions'** seeks to apply the data described in the technical volume to the workings of the local planning system and to consider their implications for future planning and land use.

The study area for this project is that of the Metropolitan Borough of Wigan, comprising about 200 square kilometres and a population of just over 300 000. This area has a long history of human occupation, of mining activity and of industrial development. These factors have all been related to, and have often been directly dependant upon, the local geology.

This volume is accompanied by nine maps showing geological information:

- Map 1 — Distribution of boreholes, pits and site investigations;
- Map 2 — Bedrock geology;
- Map 3 — Superficial geology;
- Map 4 — Hydrogeology;
- Map 5 — Mineral resources;
- Map 6 — Distribution of made and worked ground;
- Map 7 — Previous and present industrial uses;
- Map 8 — Engineering geology;
- Map 9 — Shallow mining.

The data used for the preparation of the report and the limitations imposed by the data on the usage of the report are described in **Chapters 3 and 4**, while **Chapter 5** briefly describes the topography, geomorphology and the relationship between agriculture and the agricultural soil types of the area. In **Chapter 6** a summary of the planning system at central and local level is provided, including an outline of the current guidance available from government and of some of the problems associated with information regarding adverse ground conditions; these topics are discussed at length in **Volume 2**.

Geologically, the Wigan area is underlain by rocks and soils deposited during three different periods of geological time. Upper Carboniferous rocks of about 320 to 300 million years age outcrop over the northern part of the area; these consist mainly of shales and sandstones with coal seams interbedded in the upper part of this sequence. In the southern part of the area these rocks are unconformably overlain by a southwards-thickening succession of Permo-Triassic sandstones and mudstones of around 280 to 250 million years age. The Carboniferous rocks, in particular, have been heavily faulted and folded. The geology of these bedrock deposits is described in **Chapter 7**. Most of these rocks are covered by Glacial or Post-Glacial superficial deposits of Quaternary age. The area was glaciated at least three times, the last, Devensian glaciation being the most significant in terms of shaping the landscape. Till (boulder clay) deposited from ice sheets is the predominant superficial deposit but sands and gravels deposited by melt water, laminated clays deposited in lakes, wind blown sands, organic peats formed in poorly drained areas, and alluvium deposited along more modern river valleys by flooding are also found. These deposits are described in **Chapter 8**.

Water is important to the further development of the Wigan area. Although much of Wigan's supply comes from sources outside the area, groundwater from the Permo-Triassic sandstones within the area provide a significant part of the municipal supply enjoyed locally and outside the Wigan area. Hence, development in areas where the sandstone aquifer is vulnerable to contamination must be closely monitored. This is particularly so when recent mine closures may lead to rapidly rising water levels in Carboniferous strata and the threat of highly acidic and mineralised groundwater polluting rivers and streams. Flooding is a hazard along some of the river valleys, particularly the River Douglas. The main hydrogeological characteristics of the area are described in **Chapter 9** in terms of the physical characteristics of the aquifers, the changes in water levels as a result of abstraction and the cessation of mining, and the groundwater chemistry.

The main mineral resource in the area is coal which is currently worked at three opencast sites. All underground mines are now closed. Similarly, the glass sands found in the west of the area are no longer worked as their thinness makes them uneconomic. Brickclay was formerly worked from glacial till and Carboniferous mudstones and clays. Glacial sand and gravel and pre-Quaternary sands and sandstones form potential resources for use as aggregate. Peat has been extensively worked in the south eastern part of the area for horticultural purposes and extraction continues. **Chapter 10** describes the mineral resource potential in detail.

In **Chapter 11** there is a discussion of the areas where coal mining is likely to have taken place. The methods used to investigate the presence of old workings and some of the remedial measures that might be used to stabilise them are considered. Coal extraction has taken place in the area for at least seven centuries and almost all the area where Carboniferous rocks are not covered by Permo-Triassic rocks has received the attention of miners. The particular problems associated with abandoned mine-workings include, voids close to the ground surface, subsidence when the ground collapses into near-surface workings, and unknown abandoned shafts and mine drainage adits. Modern total extraction mining is usually well recorded and subsidence is largely completed within a few years of the coal extraction.

The long history of industrial development has left an extensive legacy of human modification of the natural environment. This manifests itself by alterations to the natural ground surface, different types of waste materials deposited, major engineering works and 'disturbed' ground where excavation and deposition has taken place. These different types of made and worked ground are classified in **Chapter 12** together with the associated hazards. Gases are another potential hazard and these are considered in **Chapter 13**. Gases can be can be generated from geological sources, for example coal-bearing rocks, from other natural sources, such as by the biodegradation of organic matter in bogs and marshes, or in landfill sites. The latter is the most important source of methane and carbon dioxide in most of Britain though the Wigan area has a long association with natural methane emissions. Radon, which is generated from geological sources, and potential geological pathways, such as faults, for the transmission of all gases are also discussed.

Ground contamination, where material has been added to the environment so that the environment has become degraded with regard to present or future use, as a result of past and present land uses is a potential problem in many long established industrial areas. In some parts of the Wigan area past industrial activity has left a legacy of land which has suffered the addition of artificial and natural materials that are alien to the local environment and may be regarded as contaminants with respect to some current land uses. Site history is the principal factor that determines whether a site is likely to be adversely affected for current and future use. **Chapter 14** discusses how past industrial land uses were identified and how past uses were classified in terms of degree of contamination. Two classes were identified; firstly those industries that may have been contaminative and secondly industrial use where the potential for contamination was slight. Those areas identified as potentially contaminative were assigned to sixteen categories based on a number of government circulars and papers.

For engineering purposes the soils and rocks of the Wigan area have been classified according to their likely engineering behaviour so that all rocks having similar mass and material properties are grouped together. The properties of each of the engineering geological classes are discussed in **Chapter 15**. In addition, the behaviour of each class in terms of its suitability as a foundation material, its stability in a cut or natural slope, its excavatability and its suitability for use as engineering fill is considered. The small number of landslides that occur in the area are described in this chapter.

In conclusion, the study found that the geological factors perceived, by planners, developers and other interested parties, as being most relevant to planning and development in the Wigan area were:

- the presence of abandoned, shallow mineworkings;
- the potential for past or present industrial contamination of land;
- the potential for groundwater contamination;
- the presence of mineral resources;
- the presence of geological faults.

3 Statement of limitations

THE USE OF THIS REPORT

This work is based on existing geological maps, site investigation reports, mine plans and other reports which were collected by, or made available to, the project. Except for a small, field sampling programme for methane, radon and carbon dioxide, no new data were obtained. It must be stressed that the information provided on the thematic maps and in the technical and planning reports is interpretive, of variable quality and is distributed unevenly.

Other data may exist, which were not available to the project, that would add to the information shown on the maps and some of the geological information shown on the maps is known to require resurvey and updating. Where possible those areas in need of revision are indicated. It is possible that there are relevant features in the area, such as old shallow mining or past industrial use, for which no record was made at the time or for which records have been lost.

Consequently the maps and reports should only be used as a guide for general planning purposes and pre-site investigation desk studies. They cannot be used as a substitute for site specific investigation but should be regarded as a reference source providing a regional context and guide to the design of the necessary site investigation procedures for the site of interest. Each map has only a limited descriptive key and it is strongly recommended that the maps should be used in conjunction with the reports which contain more detailed descriptions and indicate the limitations of the information portrayed. The report and associated database may be used as a guide to more detailed sources of information such as the collection of non confidential boreholes and other data which comprise the British Geological Survey, National Geological Records Centre data collection. These include 1:10 000/10 560 geological standards, open file reports and the original field slips from the geological survey of the area.

Attention is also drawn to other sources of information and advice which should be consulted, such as the National Rivers Authority and the Coal Authority, in terms of water, mining and other specific interests.

4 Introduction

AIMS AND OBJECTIVES

The data described in this report were obtained during a three year research contract, Reference PECD 7/1/438, commissioned by the Department of the Environment in 1992. The work was carried out by the British Geological Survey (BGS) in collaboration with Roger Tym and Partners (RTP). The BGS carried out the geological aspects and thematic map production and RTP were responsible for the planning aspects.

The aim of the research was to provide concise accessible advice on the relevance of geological conditions to strategic land use planning in the Wigan area, which would also provide a regional context for site investigations.

The broad objectives of the work were:

- to establish the range of available earth science data and to bring these together in a comprehensive, concise format;
- to produce a set of applied geological maps depicting particular issues or themes relevant to land use planning in Wigan;
- to produce a derived summary map of the main planning considerations applicable to Wigan.

The results of the work are set out in a report which comprises two volumes. 'A geological foundation for planning' is a technical volume and contains a series of nine maps showing geological information:

1. Distribution of boreholes pits and site investigations
2. Bedrock geology
3. Superficial geology
4. Hydrogeology
5. Mineral resources
6. Distribution of made and worked ground
7. Previous and present industrial uses
8. Engineering geology
9. Shallow mining

The second volume, 'A user's guide to Wigan's ground conditions', is a planning-based volume and includes a summary map (Map 10) showing the main geological planning considerations applicable to Wigan.

INFORMATION SOURCES

The project was restricted to the collection and use of existing data with the exception of a small field survey to determine the methane, carbon dioxide and radon gas potentials of the geological deposits in the Wigan Metropolitan Area. Confidential data were used in making regional interpretations but in such a way that no confidential data were revealed in the reports or maps. The principal data sources used were:

British Geological Survey

Geological maps at 1:10 560, 1:10 000 and 1:50 000 scale, geological field slips, hydrogeological records, library holdings (serials and books) and archive material. In the BGS data collection 1200 relevant borehole records and 25 site investigation reports were identified. These have been added to in the course of the project and are shown on Map 1.

Wigan Metropolitan Borough

Wigan Metropolitan Borough made available to the project a large number of site investigation reports, information on contaminated land and other data.

British Coal — deep mining

Thirty seven seam plots at a scale of 1:25 000, comprising working outlines for individual seams, and a mine entry plot at a scale of 1:25 000 were obtained.

British Coal — opencast

Opencast completion plans with details of seams and lithology were obtained. An extensive collection of data about sites which have been prospected but not worked was already held at the BGS.

Air photographs

A complete, stereographic, aerial photographic cover of the Wigan Metropolitan Area, comprising 592, 9″ × 9″, black and white, panchromatic photographs at a scale of 1:6000, flown in 1992, was purchased for the project. Additional photographs were available at the Greater Manchester Geological Unit (GMGU) which also held complete sets of panchromatic aerial photographs from the 1960s and 1980, some cover in the east from the 1940s and a complete set of colour prints flown in 1989/90.

Wigan and Leigh College of Technology/Salford Mining Museum

A collection of material relating to the local geology gathered by the Wigan and Leigh College of Technology, including a collection of mine plans deposited there by the mining companies which operated in the area before 1947, is currently kept by The Salford Mining Museum.

Greater Manchester Geological Unit

A large amount of data was made available by the GMGU. Details are as follows:

1. Aerial photographs
2. Minerals Local Plan for Greater Manchester

3. Minerals workings survey with plans 1982 and 1988. These show known disused and extant quarries/pits and their state of restoration.
4. Landfill gas study for the Wigan area. A listing and map of landfill sites and gas production potential at 1:25 000 scale (confidential)
5. Mines and Quarries Inspectorate. Known mines and shafts shown on 1: 10 000 maps with accompanying reports.
6. Planning applications for waste disposal/landfill reports, indexed by 1:10 000 map
7. Landfill sites — maps and reports dating back to the 1940s
8. Applications for mineral workings. 1:10 000 maps and reports
9. Results of shallow drilling for minerals undertaken by the Greater Manchester Council

North West Water

Sixty-five site investigation reports within the area of interest were made available to the project by North West Water.

National Rivers Authority

The National Rivers Authority supplied information on mine drainage, basic aquifer properties, hydrogeology of the Coal Measures, flashes and water quality.

Civil engineering consultants

Several civil engineering consultants who were active in the Wigan area allowed the project to use information from site investigation reports which they held.

DATABASE

A database of the information collected during the project was compiled using D base 3+. The database was designed to be flexible, evolving as the data were entered and the need for refinement was identified. It was linked to Intergraph Microstation for spatial display of vector and raster data thus enabling on-screen analysis. A database user's guide is included in Appendix I. This contains installation instructions and guidance on the use of the database. Copies of the database are held by the British Geological Survey, the Department of the Environment and Wigan Metropolitan Borough Council.

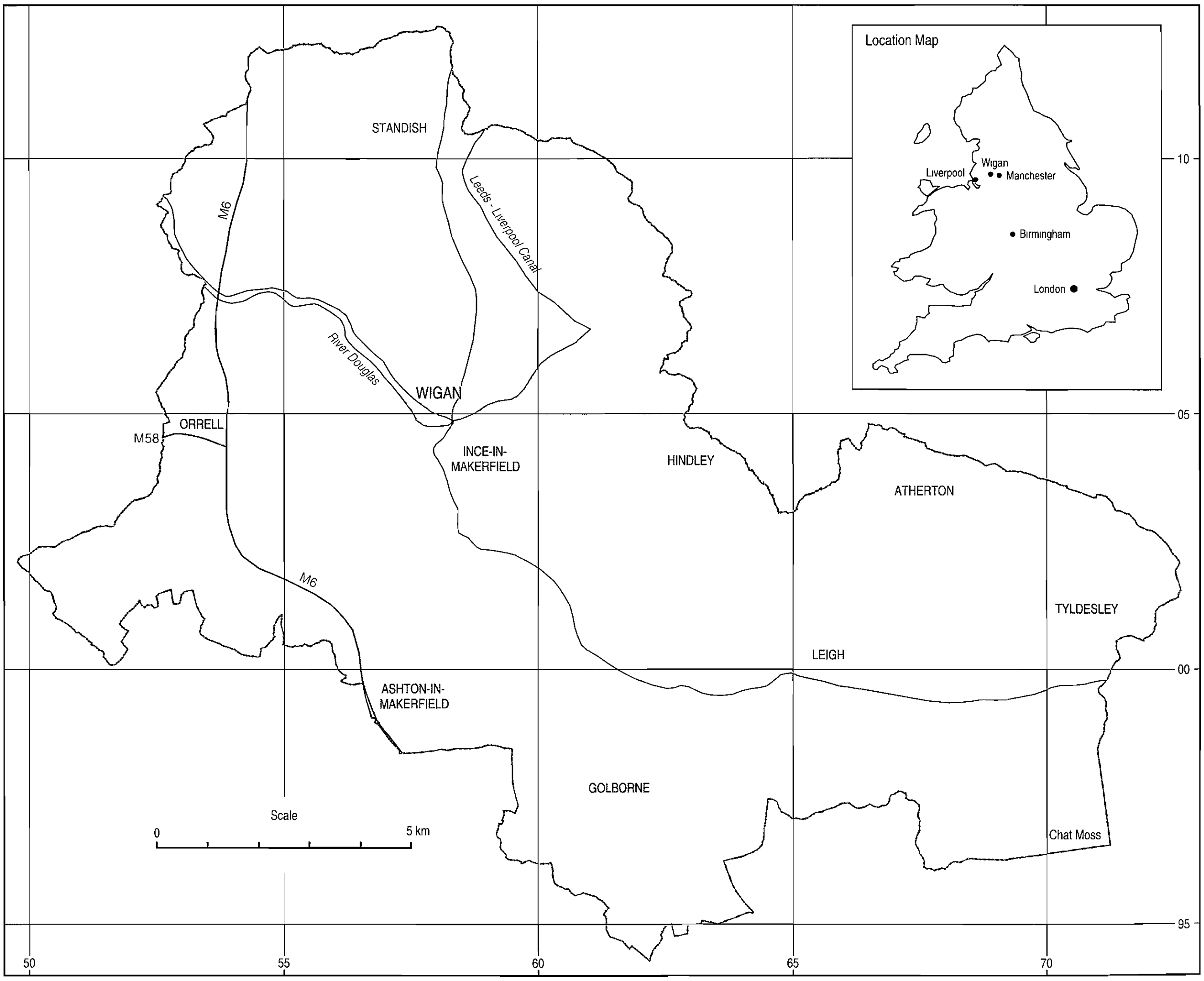


Figure 1 Location of the study area.

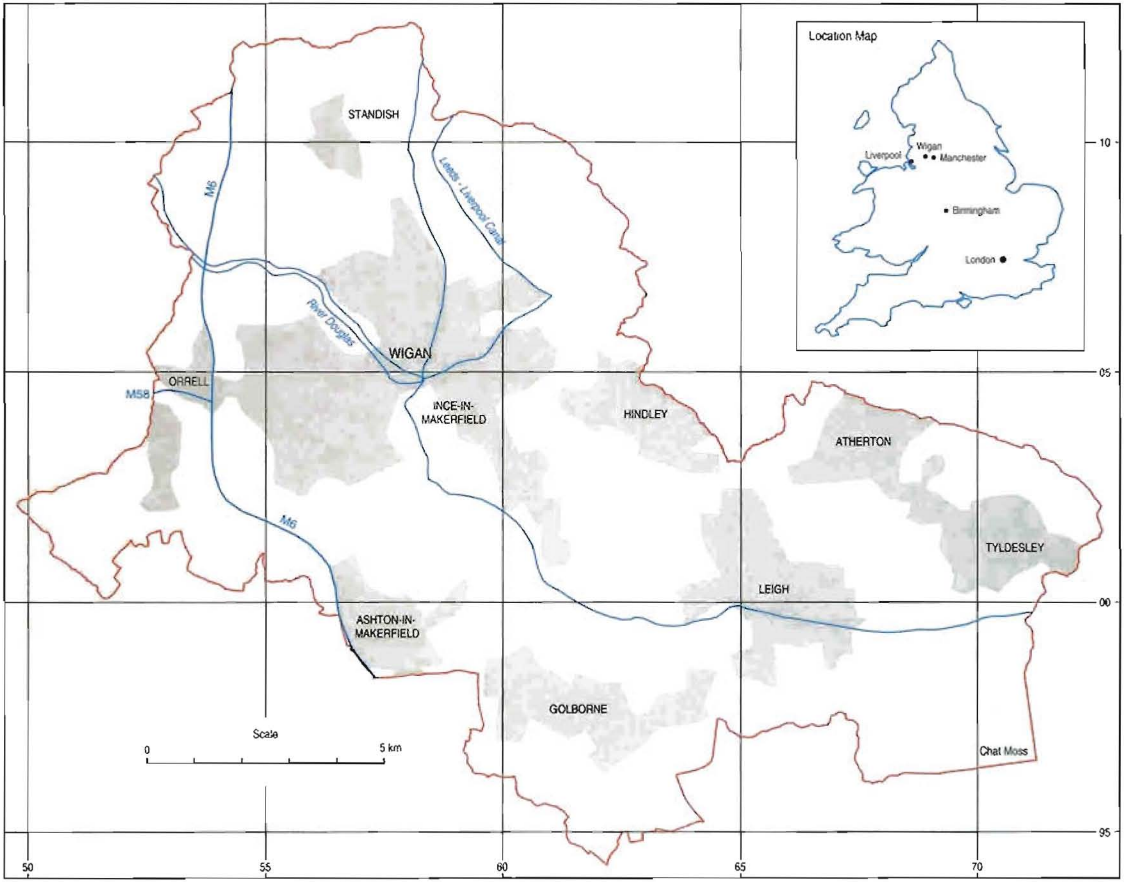


Figure 1 Location of the study area.

5 Geographical background

LOCATION

The Metropolitan Borough of Wigan lies between Liverpool, 25 km to the south-west and Manchester, 27 km to the east-south-east (Figure 1). It was formed in 1974 from the amalgamation of Wigan, Leigh and a number of small industrial and rural communities which surround them. It comprises about 200 km^2 and supports a population of about 306 000. During the course of the Applied Geological Mapping project, on the 1st of April 1994, the boundaries of the Metropolitan Borough were altered. These changes have been indicated on the boundaries of the thematic maps which accompany this report.

TOPOGRAPHY

Topographically Wigan is, generally, an area of gently undulating scenery. To the south, along the A580(T) and around Chat Moss in the south-east, the land is relatively flat with an elevation of around 20 to 40 m above sea level. The land becomes more undulating to the north and reaches elevations of about 120 to 150 m above sea level around Haigh and Aspull. Steep slopes generally are uncommon but occur locally, such as along the banks of the River Douglas which crosses the Borough from north-west to south-east. In much of the area the topography has been altered artificially. In the urban and industrial areas there are large areas of made ground, disturbed ground and excavation. In other areas which have been undermined, the land has been lowered in elevation. In some places this has caused the formation of extensive flooded areas called flashes. In contrast areas such as Chat Moss have been drained, improved and brought into agriculture or worked for peat.

GEOMORPHOLOGY

Geomorphologically the area is considered to be part of the low-lying south-west Lancashire Plain (Rodgers, 1962). The essential character of the plain derives from the predominance of glacial and more recent sediments which mask the underlying Triassic and Carboniferous bedrock. A brief summary of Quaternary history is given in Chapter 8. If further information is required reference may be made to some of the many publications which discuss the regional setting and Quaternary development of the Lancashire Plain these include papers by Bowen (1991), Johnson (1985a, 1985b), Longworth (1985) and Thomas (1985).

HISTORY OF DEVELOPMENT

Wigan has a long history which goes back at least to the Roman occupation of Britain. However, little is known of its early development. Documentary records are increasingly available from the time of the Norman Conquest onward and by the eighteenth century Wigan was a significant town with an expanding industrial base. Its industrial development is described in Chapter 2 of Volume 2 of this report.

AGRICULTURE AND SOIL TYPES

Although much of Wigan is urban or industrial, some two thirds of the area is open land used for amenity or agriculture. The agricultural soils of the Wigan area are often thin and of poor quality. They are shown on the Soil Survey of England and Wales 1:50 000 sheet 108 'Soils of the Liverpool District' and 1:250 000 sheet 3 'Soils of Midland and Western England'. They comprise mainly the Brickfield series but include lesser areas of the Ormskirk, Newport, Clifton, Rivington, Salop, Sollom, Wick and Salwick series. Large areas of an urban or industrial nature are shown as 'disturbed soils' or 'unsurveyed'.

The Brickfield, Clifton and Salop series soils are associated with areas of till and are surface water gley soils, which are slowly permeable, seasonally waterlogged, prominently mottled soils. They are suitable for permanent grassland for stock rearing, dairying and possibly cereal growing in some areas.

The Ormskirk and Sollom soil series are associated with the outcrops of the Shirdley Hill Sand and Glacial Sand and Gravel. They are podzolic acid soils with a black, dark brown or ochreous subsoil layer enriched in iron and humus. They may be suitable for the arable cultivation of cereals, potatoes, field vegetables, horticultural crops and, in places, short term grassland.

The Newport, Rivington, Salwick, Bridgnorth and Wick soil series are Brown Soils, deep or moderately deep, dominantly brownish or reddish soils with no prominent mottling or greyish layers above 0.4 m depth. They are permeable, well-drained sands, loams or clays often associated with the outcrop of the Permo Trias. They are suitable for a variety of uses including arable crops, forestry and grassland.

In the south-east of the area the moss lands give rise to organic, peat soils of the Turbary Moor series which are derived from decomposed plant remains accumulated under waterlogged conditions. These are very acid, fibrous or semi fibrous peats with well aerated and structured topsoil containing few recognisable plant remains. They are suited to a variety of agricultural uses, if drained, such as grassland, cereals or vegetable production.

6 Planning background

GROUND CHARACTERISTICS AND THE PLANNING SYSTEM

The principal aim of this study is to provide advice on the ground characteristics of the Wigan area in a form that can be used directly by planners, developers and conservation interests. It is intended that the study should broadly influence the strategic planning of land uses in the Wigan area and provide a regional content for site investigations.

This section outlines the planning system at central and local level, outlines the current guidance available from government and indicates some of the problems associated with information regarding adverse ground conditions. The relevance of ground conditions, as perceived by a number of interested groups, and the implications of applied geology for planning in the area are examined in detail in volume 2 of this report 'A user's guide to Wigan's ground conditions'.

The planning system in England and Wales was greatly strengthened by the Town and Country Planning Act of 1947 which came into operation in 1948. The two key features of this legislation, the development plan system and the control of development, have not changed fundamentally since that date. Legislation is currently consolidated in the Town and Country Planning Act 1990, as added to and amended by the Planning and Compensation Act 1991. The 1990 Act places responsibility for running the planning system primarily in the hands of local authorities, although the Secretary of State for the Environment (in Wales, the Secretary of State for Wales) has considerable supervisory powers.

DEVELOPMENT PLANS

Development plans are mandatory documents prepared by local authorities and constitute a blueprint for planning policies for an area over a 5 to 15 year period. They provide the context for determining planning applications and identify sites for new development and for redevelopment. In much of England and Wales there is a two tier system of development plans with counties producing structure plans, setting out strategic policies, and district authorities producing local plans giving detailed policies and land allocations.

The area covered by the present study is almost exactly that administered by Wigan Metropolitan Borough Council (Wigan MBC). When the Greater Manchester County Council was abolished in 1985, Wigan MBC became a unitary planning authority with responsibility for both strategic and local planning. As such Wigan MBC is required to produce a Unitary Development Plan (UDP) as the sole development plan covering all of the Borough and providing both a strategic planning framework and a detailed and local basis for the control of development. Wigan MBC's planning powers also include provision for, and control over, both waste disposal and mineral workings.

Thus the draft Wigan UDP is primarily concerned with the use and development of land within the Borough. It covers the period up to 2001. Preparation of the UDP has proceeded through the required statutory steps and the UDP is expected to be formally adopted by 1996.

DEVELOPMENT CONTROL

The control of development is the second key feature of the planning system and is the mechanism by which the policies and proposals of the development plan are used, with other material considerations, to decide whether individual planning proposals should proceed. Planning law includes a comprehensive definition of 'development' which comprises building, engineering, mining and other operations, as well as any material change in the use of land or buildings. All development as defined, bar some relatively small exceptions, requires planning permission from a local planning authority — Wigan MBC in the case of the Wigan area.

Thus for most development proposals an owner or developer must submit a planning application and secure permission. If the local planning authority refuses permission, or fails to determine an application within 56 days (a deemed refusal), or grants permission subject to any condition which the applicant considers unreasonable, then there is a right of appeal to the Secretary of State.

In submitting an application the applicant should provide sufficient information for the authority to make an informed decision. For certain major proposals this may involve the submission of an environmental assessment. The planning authority are required to seek the views of various parties and will usually also seek the views of the public at large. The planning authority is also responsible for enforcement of the planning system, whether against unauthorised development or in cases where planning conditions are infringed.

GOVERNMENT POLICY ADVICE AND GUIDANCE

In order to provide a common source of guidance and to ensure that planning decisions broadly reflect government policy, the Department of the Environment issues advice to local planning authorities, developers and other parties with an interest in the planning system in England and Wales. This advice comprises circulars and guidance notes:

Regional Planning Guidance:

RPG4	Strategic guidance for Greater Manchester (1989)

Planning Policy Guidance Notes:

PPG1	General policy and principles (1992)
PPG2	Green belts (1995)
PPG3	Housing (1992)
PPG4	Industrial and commercial development and small firms (1992)
PPG6	Town centres and retail development (1993)

PPG7 The countryside and the rural economy (1992)
PPG9 Nature Conservation (1994)
PPG12 Development plans and regional planning guidance (1992)
PPG13 Transport (1994)
PPG14 Development on unstable land (1990)
PPG15 Planning and the historic environment (1994)
PPG16 Archaeology and planning (1990)
PPG17 Sport and recreation (1991)
PPG21 Tourism (1992)
PPG23 Planning and pollution control (1994)
PPG24 Planning and noise (1994)

DoE Circulars:

15/88 Assessment of environmental effects
17/89 Landfill sites: development control
1/92 Planning controls over sites of special scientific interest
30/92 Development and flood risk

Mineral Planning Guidance Notes:

MPG1 General considerations and the development plan system (1988)
MPG2 Applications, permissions and conditions (1988)
MPG3 Coal mining and colliery spoil disposal (1994)
MPG4 Review of mineral working sites (1988)
MPG5 Minerals planning and the General Development Order (1988)
MPG6 Guidelines for aggregates provision in England (1994)
MPG7 Reclamation of mineral workings (1989)
MPG10 Provision of raw material for the cement industry (1991)
MPG11 Control over noise at surface mineral workings (1993)
MPG12 Treatment of disused mine openings and availability of information on mined ground (1994)

Derelict Land Grant Advice:

DLGA1 Derelict land grant policy (1991)

In addition to the above, revised government guidance is under preparation for:

- General mineral planning considerations. (draft revision of MPG1)
- Landslides and planning (Draft annexe to PPG14, Development on unstable land)

THE PLANNING SYSTEM AND INFORMATION ON GROUND CONDITIONS

The planning system is concerned with the use and development of land. The current system has its origins in physical planning related to public health and housing, although social and economic factors have subsequently played increasingly major roles. Nevertheless the nature of the ground is important in making planning decisions, particularly in the light of broader environmental considerations which have become prominent over the past 10 to 15 years.

There are many ways in which ground conditions can influence the planning system with regard to existing and proposed developments. They include ground stability, the risk of flooding, sterilisation of mineral reserves, the possible contamination of groundwater supplies, and the potential for underground gas migration.

The extent to which existing ground conditions represent a (potential) opportunity or threat for planning and development varies with the perspective of the different groups of people who participate in the planning system. Likewise, these groups have different needs for ground condition information and varying levels of technical knowledge with which to interpret such information. In order to examine more accurately the relationship between the planning system and ground conditions this study has sought to differentiate between three broad groups with an interest in applied geological mapping in the Wigan area as follows:

(a) Those with a public sector responsibility to have regard for planning and development across the whole Wigan area.

(b) Those with a commercial interest in developing or redeveloping specific sites and/or buildings — primarily developers and landowners.

(c) Those with a specific interest in environmental conservation — primarily conservationist groups with an active and specific interest in the Wigan area.

There is obviously some degree of overlap between these three groups but they do represent different perspectives and preferences as to whether, where, when and how development should proceed. The objectives of each group, their need for ground condition information and the interaction between the planing system and ground condition information is considered in detail in Volume 2 of this report.

AVAILABILITY AND SENSITIVITY OF GROUND CONDITION DATA

It became apparent during the initial phase of the study that comprehensive information on ground conditions was not available in the Wigan area. A fundamental cause of this situation is inadequate recording of activities such as early mineral extraction, waste disposal and contaminative land use. When data are available it may be difficult to gain access to them since some holders of local data may be reluctant to make them available due to concern over their misinterpretation, financial implications, or fear of legal implications. Data on sites prone to gaseous emissions, for example, may have a negative impact on the local economy by affecting the value of property and possibly damaging inward investment. However, although adverse ground conditions are an important issue for planners, developers and conservationists in Wigan and they often represent constraints on development, there is broad agreement for the need to improve them.

Previously there has been insufficient information relating to ground conditions in the Wigan area and the lack of full information has caused some degree of uncertainty, increased risk and economic disadvantage. Consequently, there has been widespread support for greater access to ground condition information and for the collection and collation of a wider range of good quality data.

USE OF DATA TO SECURE GRANTS FOR LAND RECLAMATION

There are a variety of public sector funding mechanisms which are designed to encourage local authorities, landowners and developers to reclaim and re-use derelict land. The two most common mechanisms in the recent past have been the Derelict Land Grant (DLG) scheme and the City Grant scheme. The new Single Regeneration Budget administered for the Wigan area by the Government Office for the North West now replaces the latter.

The output from this study is intended to assist the local authority, intending developers, the Department of Environment, English Partnerships and the Government Office for the North West in gaining sufficient information on ground conditions to make best use of available land and in particular, to enable hard land uses for reclaimed sites.

Wigan MBC, as a public sector body, will usually be able to seek and, hopefully, secure grant assistance for site investigation works. However, for private sector developers, the mechanics of current funding regimes are such that monies are not made available unless a scheme of reclamation actually proceeds following the site investigation. Thus developers have a financial temptation to reduce site investigation to a minimum. The wider availability of ground condition data would substantially help to rectify this constraint.

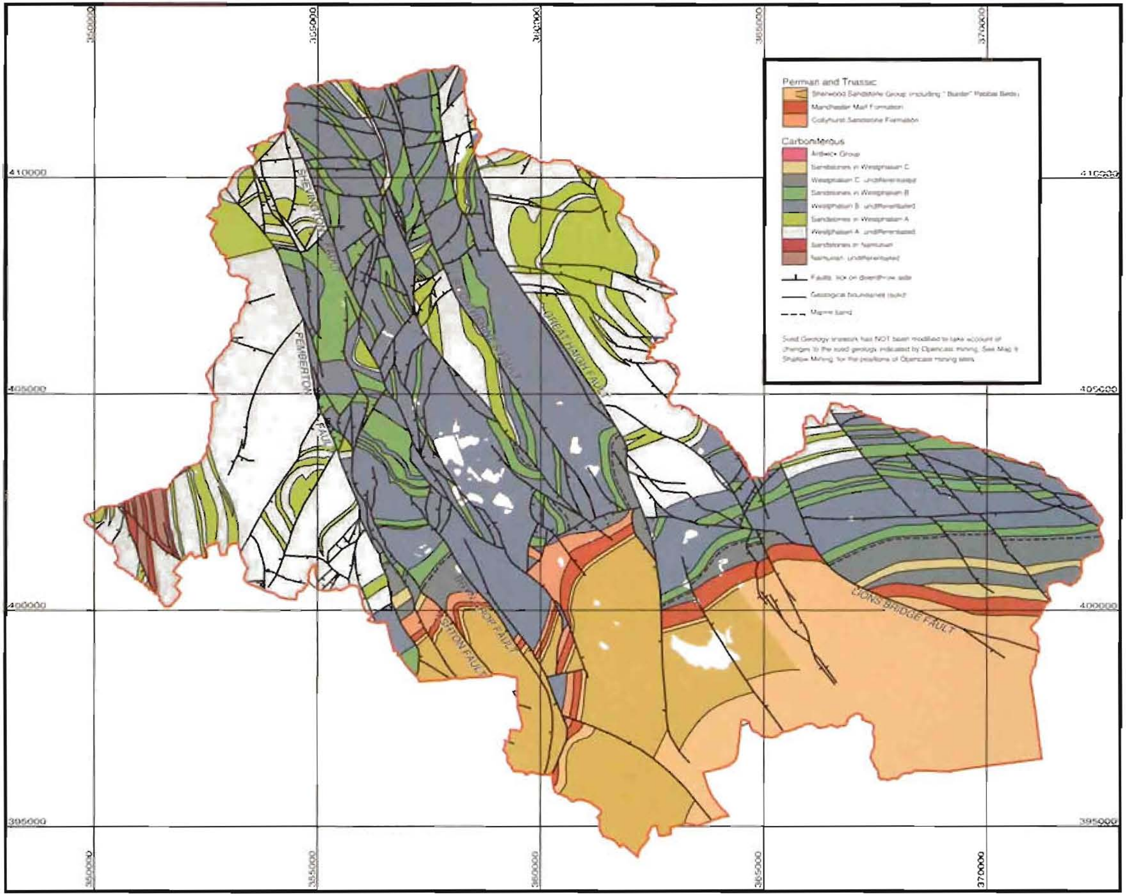


Figure 2 Simplified bedrock geology (reduction of Map 2).

7 Bedrock geology

INTRODUCTION

The Bedrock Geology map (Map 2) depicts the distribution of the different rock types which outcrop at rockhead. It does not depict superficial deposits, and may be read as though these deposits have been stripped away.

Geology is an interpretative science. A geological map is a two dimensional representation of the interpretation of three dimensional information. The information on which the interpretation is based is usually sparse. An understanding of the environments in which the rocks were deposited and the depositional processes acting at the time are crucial in predicting the geology in areas where few data exist.

In the Wigan area the bedrock is composed of rocks deposited during two different periods of geological time. Upper Carboniferous rocks of about 320 to 300 million years age outcrop over the northern part of the area, while in the southern part these rocks are unconformably overlain by a southwards thickening cover of younger (around 280 to 250 million years old) Permo-Triassic rocks.

A simplified map of the outcrop pattern, Figure 2, is shown and Map 2 (Bedrock Geology) gives greater detail. Map 2 is at a scale of 1: 25 000 and is derived from surveys at the 1:10 560 scale (Six inches to the mile) by Geological Survey geologists during the 1920s and 1930s. This map is not intended for use at larger scales and any attempt to enlarge the map may imply a spurious accuracy. At larger scales significant improvements can be made, by the use of existing data and additional field survey, to the position of coal outcrops and sandstone/mudstone boundaries. If required a more detailed interpretation of the geology or site specific studies may be obtained from the British Geological Survey.

The generalized vertical section, Figure 3, shows the geological succession, and includes all the bedrock units

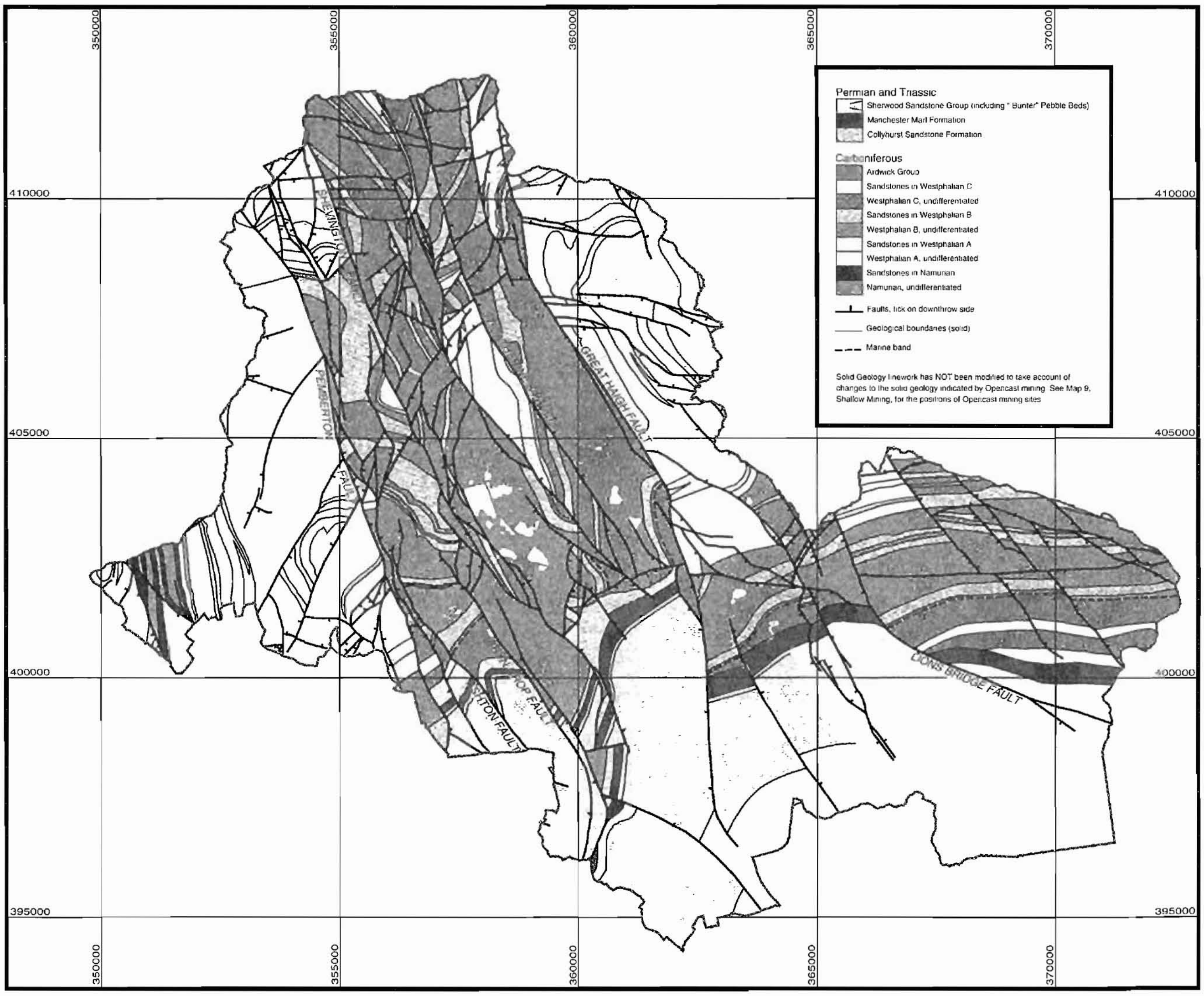
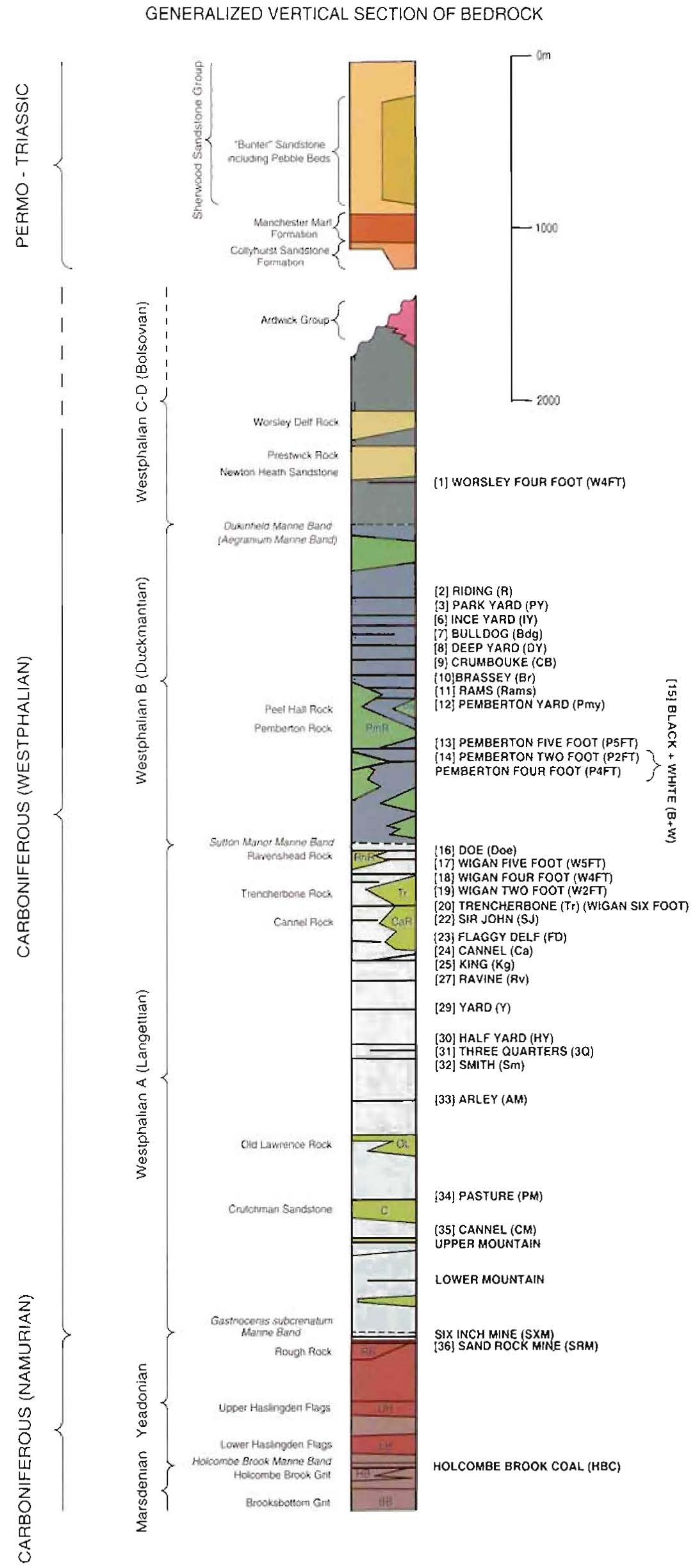


Figure 2 Simplified bedrock geology (reduction of Map 2).

Figure 3 Generalised vertical section (from Map 2).



presently known below the surface. It may be used to estimate the succession beneath an area. For instance a boring located on an outcrop of the Arley Mine Coal, should encounter the succession depicted occurring below the Arley Mine Coal on the section.

Owing to an extensive and thick cover of superficial deposits, the bedrock in the Wigan area is very poorly exposed, and its sequence has been established, mainly, from mine shaft and borehole records. Where drift cover is thick, the quality of the subcrop map is largely dependant on the quantity and quality of sub-surface data. In the Coal Measures, where extensive mining has occurred, mine plans provide an excellent basis for understanding the geological structure. Using the proven vertical succession of geological units and their inclination, it is possible to calculate how and where these units outcrop at rockhead. At the time of the last survey coal production was at its maximum and mine plans from most of the Wigan area were available. However, the thickness of the drift or the elevation of the rockhead must also be known and this information was sparse at that time.

The current study has collected a large amount of information on the nature of the bedrock geology in the form of boreholes and trial pits. The locations of these data are shown on Map 1, and further details are contained in the database.

UPPER CARBONIFEROUS

Depositional environments

During the Namurian period, when the oldest rocks (approximately 315 million years) outcropping in the Wigan area were deposited, the Lancashire area lay within a large, actively subsiding basin inundated by the sea. Extensive delta systems, fed with sediments eroded from the surrounding land surfaces, built out into the basin. As may be seen in modern delta systems, coarser grained sediments (up to coarse sandstones) were deposited where delta systems were active, while fine grained background sedimentation, usually of mud-sized sediments, occurred in more quiescent areas of the basin. Toward the end of the Namurian, sedimentation periodically outstripped subsidence, and peaty swamps covered by dense forests of horsetails, club mosses, tree ferns and primitive conifers were established. Variations in sea-level are reflected by distinct cycles of sedimentation, each beginning at a high sea-level stand with the deposition of marine or near-marine shales (including fossiliferous 'Marine Bands') which pass up through mudstones into deltaic siltstones and sandstones. The top of each cycle, when sea-level is at its lowest, is marked by the formation of soils and the development of a widespread cover of vegetation. Once subjected to compaction and lithification the soil horizons become seatearths, and the organic deposits coals. This pattern of deposition is repeated with each rise in sea-level. The deposits of an individual cycle are known as a cyclothem. The sequence of development described is idealised and may be interrupted or modified.

Through Westphalian times, from 315 to about 300 million years ago, the same pattern continued but with increasing dominance of shallow-water deposits. The cycles increased in number but became, generally, thinner. Periods when the area was above sea-level and land floras were abundant became more frequent and, in many cases, more prolonged, resulting in complicated patterns of coal seam development. Although the general range of lithologies deposited is the same as during the Namurian period, the lateral development of, and inter-relationships between, the different lithologies is far more complex, reflecting the different environments of deposition found in a large delta complex. The rocks deposited prior to the Westphalian are collectively known as the Millstone Grit Series, while those deposited during the Westphalian are collectively known as the Coal Measures.

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 time when a great thickness of the Carboniferous strata was removed by erosion. The resulting land surface was subjected to tropical weathering and the denuded Carboniferous rocks were superficially reddened by surface weathering.

Millstone Grit Series

Namurian rocks of the Marsdenian stage

The oldest rocks occurring at the surface in the Wigan area are sandstones and mudstones of Marsdenian age, which outcrop against the Upholland Fault on the west side of Billinge Hill. The presence of Marsdenian sediments was proved by an exposure of a marine band containing *Gastrioceras cancelatum Bisat* three km north of the Wigan boundary. Only the upper one and a half cycles of the Marsdenian sediments outcrop below this exposure. The coarse Brooksbottom Sandstone, the lowest unit exposed in the area, is overlain by a thin coal. The succeeding cycle also culminates in development of a thick sandstone, the Holcomb Brook Sandstone, overlain by a coal of the same name. Neither of the two coals mentioned is thickly developed, and neither has been exploited. These two sandstones form well developed topographic features, which can be traced along their strike into the Wigan area.

Little is known about the sequence occurring beneath the Brooksbottom Sandstone in this immediate area. A number of early oil-exploration boreholes were drilled out to the west of Wigan, including wells at Upholland (1522 m) and Formby (2340 m) (Kent 1948). The Upholland G1 borehole proved a total of 420 m of Marsdenian sediments, and probably entered the top of the underlying Kinderscout Group.

Namurian rocks of the Yeadonian stage

The measures between the *Gastrioceras cancelatum* and the *G. subcrenatum* marine bands, which mark the top and bottom of the Yeadonian stage, total some 190m in thickness, and are dominated by fine-grained lithologies. Two major cyclothems, separated by a marine band, are present.

The lower cyclothem has been described in detail from the area to the north of Wigan by Collinson and Banks (1975). The lower beds are not exposed but are presumed to comprise marine shales. These pass upwards into distinctive fluvio-deltaic, flaggy, fine sandstones, the Lower Haslingden Flags, which are incompletely exposed in the Upholland area. The upper cyclothem has been studied by Maynard (1992a), who defined a number of new formations. In the Wigan area, fine-grained marine shales (Naden Brook Shale Formation) are succeeded by, first, non-marine shales (Upper Haslingden Shale Formation) and, then, by fine-grained, grey-brown, quartzose sandstones with little mica (Upper Haslingden Flags Formation). This latter formation is interpreted as a distal delta deposit, on the southern flank of an east–west elongated linear delta, being supplied from the west. Maynard (1992a) interpreted the Upper Haslingden Flags delta to be time equivalent to the one depositing the Rough Rock Flags, which extended into the Pennine Basin from the north and east.

Over most of the northern Pennine Basin the upper part of the cyclothem is marked by the development of the Rough Rock, a coarse, yellow–brown, pebbly sandstone. In the south Lancashire area the Rough Rock is generally present in two leaves separated by a coal seam, the Sand Rock Mine. However, in the west of the Wigan area the Rough Rock is only weakly developed or absent. The Sand Rock Mine is thickly developed and has been extensively worked near crop.

The stratigraphy of the Upper Yeadonian — Westphalian boundary in the Billinge Hill area was revised by Eager et al. (1991). On the basis of new fossil evidence they proved that the original correlation of the stratigraphy of the area was incorrect. What had been called the 'Lower Mountain Mine' coal seam was the 'Sand Rock Mine' seam. However, British Coal mine plans currently use the original terminology. The top of the cyclothem, and the top of the Yeadonian stage, is marked by the development of a thin coal, the Six-Inch Mine, which was formerly exposed in the Upholland cutting.

Coal Measures

The deposits of the Westphalian are collectively known as the Coal Measures. They are difficult to subdivide because of their rhythmic, repetitive nature and consequently a number of classification schemes have been used, the relationship between them is illustrated in Figure 4 (Ramsbottom et al., 1978).

The scheme now used in this area is shown on the vertical section, Figure 3 taken from Map 2, and is based on the age of the strata. Four divisions (Stages) are recognised (from oldest to youngest the Westphalian A, B, C and D) separated by widespread marine bands. Although now obsolete in geological terms, the subdivision into Lower, Middle (or Productive) and Upper Coal Measures is still, commonly, used. The Middle Coal Measures equate approximately to the Westphalian B.

Westphalian A

Westphalian A strata outcrop in the area west of the Pemberton Fault, where they dip mainly to the east and south, but with considerable local variation. They also outcrop east of the Great Haigh Fault, where again the dip is principally to the south, and in small fault bounded windows in the Wigan trough. In all of these areas the Westphalian A strata are conformably succeeded by, and dip beneath, overlying Westphalian B strata.

The Westphalian A is marked at its base by the *Gastrioceras subcrenatum* Marine Band and at its top by the Sutton Manor Marine Band. It is best described in two sections, the strata below and above the Arley Mine (previously the boundary between the Lower and Middle Coal Measures).

The sequence below the Arley Mine is largely barren and contains only a few widely-spaced coal seams. The full sequence from the Six-Inch Mine to the Arley Mine is exposed in the far west of the district between Longshaw Common and Billinge. The rocks immediately below the Arley Mine are exposed in the north of the area near Arley Hall. Two coal seams are of sufficient development to have been worked; they are the Cannel Mine (as distinct from the Cannel higher in the sequence) and the Pasture. The only major sandstone to outcrop is the Crutchman (or Billinge Hill) Sandstone, which forms the ridge of high ground running northward from Billinge Hill to Upholland. The exposure in Billinge Beacon Hill Quarry has been studied, in detail, by Fielding (1987). The Old Lawrence Rock, well developed to the north, is insignificant in this area. The Arley Mine has been very widely worked in the Wigan area.

The measures from the Arley Mine to the Sutton Manor Marine Band contain many important coal seams. The principal seams are, in ascending order, Arley, Smith (= Rushy Park), Three Quarters (= Cockloft), Half Yard, Yard, Yard Tops, Ravine, Queen, King, Cannel, Flaggy Delf (= Little), Sir John (= Bickershaw Yard), Peacock, Trencherbone (= Wigan Six Foot), Wigan Two Foot, Wigan Four Foot, Wigan Five Foot and Doe.

A number of major sandstones are developed in this part of the sequence. The Ravenhead Rock, immediately overlying the Wigan Five Foot Seam, is thickest in the west of the area but dies out east of Hindley. The outcrop in Winstanley Park, shown on Map 2, has since been removed entirely during opencast mining operations of the underlying coal.

The Cannel Rock and the Trencherbone Rock are thickest in the Haigh syncline in the north-east of the area, and form the high ground on which Aspull and Haigh stand. They die out quickly to the west and south, but persist along their strike to the east. They are grey-white, flaggy, current-bedded sandstones and have both been quarried. In the Haigh syncline the Trencherbone Rock has washed out the underlying Trencherbone seam and, in places, also cuts into the top of the Cannel Rock.

The Arley Mine, Smith, Three Quarters and Half Yard coal seams occur in a broad syncline beneath the township of Orrell and, collectively, make up the Orrell Coalfield. They have been heavily exploited, mostly before the introduction of systematic recording of mine workings (see Chapter 11).

The group of seams from the Ravine up to the Wigan Five Foot have been a principal target for opencast mining. Where they outcrop in the area west of the Pemberton Fault and south of the Tinker Hole Fault, all these seams have been mined. In the north-east of the area the Ravine, King, Queen, and Cannel seams have been extensively worked.

A fault bounded window of Westphalian A rocks surrounded by younger Westphalian B sediments occurs beneath the centre of Wigan, which brings the sequence above the Cannel Rock to rockhead. Extensive unrecorded mining in the Wigan series of seams has been found in this area (see Chapter 11).

Westphalian B

Strata of Westphalian B age outcrop in two main zones, one within the complexly down-faulted graben bounded on the west by the Pemberton Fault and on the east by the Great Haigh Fault and the other in a broadly east–west oriented, southwards dipping zone between the underlying Westphalian A and the overlying Permo-Triassic in the east of the district.

The coal seams of the Westphalian B occur in two groups or series. The lower (Pemberton) series comprises, in ascending order, the Black and White, Pemberton Four Foot, Pemberton Two Foot and Pemberton Five Foot seams. The upper (Ince) series includes the Pemberton Yard, Rams (= Ince Furnace), Brassey (= Ince Seven Foot),

Sub-system	Series	Stages	Index	Divisions shown on Geological Survey maps: England & Wales (Stubblefield & Trotter, 1957)	Divisions shown on Geological Survey maps: Scotland (MacGregor, 1960)	Divisions shown on Geological Survey maps: N. Devon and Cornwall	Other divisions: Trueman, 1946	Other divisions: Heerlen, 1935	Other divisions: Mesothems (Ramsbottom, 1977)
SILESIAN	STEPH-ANIAN	Stephanian C B A; Cantabrian			Upper (Barren) Coal Measures		Morganian		
SILESIAN	WESTPHALIAN	Westphalian D		Upper Coal Measures	Upper (Barren) Coal Measures		Morganian	Westphalian D	
SILESIAN	WESTPHALIAN	Westphalian C	'A'	Upper Coal Measures / Middle Coal Measures	Upper (Barren) Coal Measures		Morganian / Ammanian	Westphalian C	
SILESIAN	WESTPHALIAN	Westphalian B	'A'	Middle Coal Measures	Middle Coal Measures	?	Ammanian	Westphalian B	
SILESIAN	WESTPHALIAN	Westphalian A	G2	Lower Coal Measures	Lower Coal Measures / Passage Group	Bude Fm; Bideford Fm	Ammanian	Westphalian A	
SILESIAN	NAMURIAN	Yeadonian	G1	Lower Coal Measures	Passage Group	Bude Fm; Bideford Fm	Ammanian	Namurian C	N11
SILESIAN	NAMURIAN	Marsdenian	R2	Millstone Grit 'Series'	Passage Group	Crackington Fm	Ammanian	Namurian B	N10; N9
SILESIAN	NAMURIAN	Kinderscoutian	R1	Millstone Grit 'Series'	Passage Group	Crackington Fm	Ammanian	Namurian B	N8; N7; N6
SILESIAN	NAMURIAN	Alportian	H2	Millstone Grit 'Series'	Passage Group	Crackington Fm	Ammanian	Namurian A	N5
SILESIAN	NAMURIAN	Chokierian	H1	Millstone Grit 'Series'	Passage Group	Crackington Fm	Ammanian	Namurian A	N4
SILESIAN	NAMURIAN	Arnsbergian	E2	Millstone Grit 'Series'	Passage Group / Upper Limestone Group	Crackington Fm	Ammanian	Namurian A	N3; N2
SILESIAN	NAMURIAN	Pendleian	E1	Millstone Grit 'Series'	Upper Limestone Group / Limestone Coal Group	absent	Ammanian	Namurian A	N1
Dinantian (pars)	Viséan (pars)	Brigantian (pars)			Lower Limestone Group				

Figure 4 Correlation of the Coal Measures classification schemes (after Ramsbottom et al., 1978).

Crumbouke (= Ince Four Foot), Ince Deep Yard, Bulldog, Ince Yard, Lyons Delf, New Mines Top, Park Yard and Riding seams.

The sequence between the Sutton Manor Marine Band and the Pemberton series is dominantly fine-grained. A number of thin, but apparently impersistent, sandstones are developed but are nowhere significant.

Correlation of the Pemberton series across the area is difficult because seams show considerable variation in thickness and development. Therefore, the vertical succession also varies considerably. At outcrop in the south and east of the area, the lowest coal in the sequence is the Black and White (= Bickershaw Seven Foot/Lower Florida). The measures between this seam and the overlying Pemberton Five Foot (= Higher Florida/Windmill) are generally fine-grained, although a sandstone is developed in the area around Atherton.

Within the confines of the Wigan graben, the first recognisable seam in the succession is the Pemberton Four Foot, then the locally important Pemberton Two Foot and the Pemberton Five Foot. The intervening strata are fine-grained mudstones.

The interval between the Sutton Manor Marine Band and the Pemberton Five Foot shows considerable variation across the area, from about 70 m in the west of the area, to about 145 m in the Wigan graben and back to about 60 m in the east. This thickness variation probably reflects active faulting during sedimentation in early Westphalian B times.

Two major sandstones are developed in the interval between the Pemberton and Ince series. The Pemberton rock outcrops in numerous small, faulted blocks in the Wigan graben and achieves its maximum development of about 60 m in the Pemberton area. It persists to the south-west of the area but rapidly dies out in all other directions. Conversely, the Peel Hall Rock is only developed in the south and east of the area, where it reaches a maximum of about 30 m.

Unlike the Pemberton series, coals of the Ince series are comparatively laterally persistent and can be correlated over a broad area. The sequence in which they occur is dominantly fine-grained, with a few minor sandstones. These coals have been worked extensively by opencast mining in the area to the south-west of Wigan.

No further coals are recognised from the sequence between the Pemberton series and the Dukinfield Marine Band, which marks the top of the Westphalian B. A widespread sandstone, the Nob End Rock, occurs at the top of the interval.

WESTPHALIAN C

Strata of Westphalian C age outcrop in an elongate southwards-dipping strip running eastwards from Leigh. The base of the interval is marked by the Dukinfield Marine Band, which is known from underground evidence in the Worsley area. On the southern margin of this outcrop, the Westphalian C is unconformably overlain by Permo-Triassic rocks, resting on the pre-Permian erosion surface. This erosion surface cuts down to progressively deeper levels to the west, such that in the west of the area the Westphalian C is, in places, completely removed, while to the east some 250 m remain.

The position of the top of the Westphalian C is somewhat uncertain. In the Wigan Memoir, Jones et al. (1938) identified an unconformity between the Upper Coal Measures and overlying reddened and variegated strata occurring at depth beneath the Permo-Triassic. They termed these strata the Ardwick Group. It is now known that these reddened strata are primary red beds which are conformable with the underlying Coal Measures (Trotter, 1953). They represent a change of facies to an alluvial plain environment. The base of the Ardwick group is defined as the first incoming of variegated or reddened bedding and is diachronous. The boundary between the Westphalian C and D has not been located precisely but lies within the Ardwick Group and has been taken, provisionally, at a horizon that divides the group into a lower part, comprising red mudstones and sandstones, and an upper part which also includes several thin limestones, seatearths and coals. Secondarily reddened strata immediately underlie the sub-Permian unconformity, but they have not been distinguished from unaltered strata.

Only one significant coal seam occurs in the Westphalian C, the Worsley Four Foot seam. This has been worked extensively in the east of the area. Three widespread marine bands occur in the Westphalian C, the Manchester, Lower Sankey and Top Prestwich Marine Bands. This reversion to a stronger marine influence is also reflected in the high sulphur content of the Worsley Four Foot coal seam.

Two major sandstones occur in the measures above the Worsley Four Foot. The Newton Heath sandstone is widespread and achieves a maximum development of 45 m while the Worsley Delf Rock is some 60 m thick at its maximum development. Neither form a pronounced topographic feature.

PERMO-TRIASSIC

Depositional environments

Sedimentation recommenced in the early Permian, approximately 280 million years ago, with a change to a new tectonic regime marked by widespread regional subsidence. Semi-arid, desert or near-desert, conditions prevailed. Subsidence, briefly, exceeded sedimentation during the late Early Permian, when deposition of the Manchester Marl Formation occurred in a shallow, epi-continental sea, but the area emerged during the deposition of later Permian and Triassic sediments.

The youngest bedrock formations preserved in the Wigan area are of Triassic (probably Early Triassic) age, about 250 million years old. All subsequent bedrock deposits have been removed by erosion. The Permo-Triassic rocks of the Wigan area can be separated into three divisions, the Collyhurst Sandstone Formation, the Manchester Marl Formation and the Sherwood Sandstone Group (formerly the Bunter Sandstone and Pebble Beds) (Figure 3). They are generally soft, easily eroded, and do not form marked topographic features. The Permo-Triassic rocks are covered by superficial deposits except for a few small areas near Ashton-in-Makerfield and Golborne.

Collyhurst Sandstone

The Collyhurst Sandstone Formation consists of deep red, soft, medium to fine grained, well-sorted, non-pebbly sandstones, with abundant 'millet seed' sand grains. The beds are generally lenticular and cross-bedding is common. Cementation generally is weak and, in extreme cases, the sediments remain as very dense sand. The lack of cementation gives the formation a high primary porosity. The Collyhurst Sandstone is of wind-blown, origin, and represents fossil sand-dune deposits.

The Collyhurst Sandstone Formation has been penetrated by several deep boreholes in the south of the area. These indicate a dramatic thickness variation across the Wigan graben structure. The Collyhurst Sandstone is 70–100 m in thickness between the Pemberton and Great Haigh Faults but east of the Great Haigh Fault it is only about 3 m thick. Jones et al. (1938) interpreted this variation to be due to contemporaneous faulting; Poole and Whiteman (1955) believed it to be related, instead, to an uneven pre-Collyhurst Sandstone land surface.

Manchester Marl

The Manchester Marl is conformable on the underlying Collyhurst Sandstone. It comprises dark, brick red or chocolate-brown mudstone, with minor, interbedded sandstone and limestone. The lowest 8 to 20 m of the Formation is richly fossiliferous and yields an Upper Permian marine fauna of bivalves, algae, ostrocods, gastropods and foraminifera. Small 'fish eyes' are present at certain horizons; these are black, slightly radioactive concretions almost invariably surrounded by small grey-green halos caused by the reduction of iron oxide in the mudstones. The Manchester Marl Formation becomes coarser upwards, passing into interbedded mudstones, siltstones and sandstones which contain well-rounded, windblown sand grains. Periodic emergence is indicated by sand-infilled desiccation cracks

The base of the Manchester Marl is sharp and easily defined, being marked by a rapid transition from the underlying Collyhurst Sandstone, but its upper boundary is transitional with the overlying Sherwood Sandstone Group. The Manchester Marl is interpreted as a shallow, continental sea deposit with the marine influence decreasing with time and being replaced by sedimentation in an arid, continental environment.

The position of the Permian-Triassic boundary is not known. The Manchester Marl Formation is of Upper Permian age but no definitive fossil material is known from the Sherwood Sandstone Group.

Sherwood Sandstone Group

The Sherwood Sandstone Group is not well known in the Lancashire area. In general, it comprises soft, red-brown, fine to medium-grained sandstone with beds of coarser well-rounded sand grains. A distinct facies, the Chester Pebble Beds (formerly known as the Bunter Pebble Beds) which contain well-rounded pebbles of quartz and quartzite, either randomly scattered or in crude lamination can be distinguished from the otherwise uniform Sherwood Sandstone Group. The sub-division of the Sherwood Sandstone Group into three units: the Lower Mottled Sandstone, the Bunter Pebble Beds and the Upper Mottled Sandstone, has been discontinued.

STRUCTURE

The present disposition of the strata of the Wigan Coalfield is the result of a long history of deformation of the earth's 'crust'. Such deformation is a result of major movements of the earth's 'crustal plates' and is manifested by folding and faulting. The major faults present in the Wigan area are shown in Figure 5.

In the Wigan area folding occurs on two scales. Firstly, there are large (km) scale, open folds probably related to regional compression. These are not immediately obvious to the eye, being much obscured by later faulting, but result, for instance, in the regional swing in orientation of strata near Winstanley. Secondly, there are smaller (10's–100's m) scale, tighter folds, caused by the 'drag' of strata against fault planes during fault movement.

Faults in the Wigan area display a normal sense of displacement and were probably developed in an extensional tectonic environment. The position of a fault shown on a map is based on the interpretation of topographic features, surface outcrops and underground mining data but the evidence is rarely sufficient to locate a fault precisely. In an area of thick and extensive superficial deposits, such as Wigan, data regarding the bedrock surface are not available, and the positioning of faults relies almost entirely on projection from underground mining information. Studies of coalfield faulting have shown that the majority of faults have a dip of around 70° (Rippon, 1985; Walsh and Watterson, 1988). Therefore, the sub-drift (rockhead) position of a fault, proven underground, can be estimated by projecting upwards at this angle. However, as only a slight variation in the fault inclination would result in an incorrect projected position, the fault shown on the map must be regarded as a best estimate. It is important to understand the nature of geological faults and the uncertainties which attend their precise position at the surface when using geological maps.

Geological faults in this area are of ancient origin. They are currently inactive tectonically. However, they may be reactivated by undermining, when general subsidence effects may be concentrated along them, or by quarrying if a fault plane dips out of the excavated face. Underground mining has ceased in the Wigan area and fault reactivation is unlikely to result from any residual subsidence that may still occur.

In the Wigan area a number of major periods of faulting and folding have been identified:

Pre-Carboniferous structures

Most of the principal faults in the Wigan area probably started as pre-Carboniferous structural lineaments which have been repeatedly re-activated during subsequent deformation events. Two pre-Carboniferous structural trends are present, namely: north-west-trending (Charnian) and north-trending (Malvernian).

Carboniferous structures (early Carboniferous to Westphalian C)

The Pennine basin in northern England was formed by crustal extension in the Early Carboniferous, as a series of half grabens. This was succeeded by a phase of thermal subsidence in the Upper Carboniferous (Leeder and McMahon, 1988), characterised by a sedimentary fill of cyclothems. Variations in the rate of subsidence are reflected by variations in the thickness of cyclothems (Maynard, 1992a). Towards the end of the Namurian, and continuing through Westphalian times, the rate of subsidence slowed and sedimentation kept pace with subsidence, resulting in long periods of relative stability during which thick peat deposits accumulated.

The main influences on sedimentation patterns during the Westphalian A to C appear to have been syn-sedimentary, faulting and consolidation-induced subsidence. Guion and Fielding (1988) suggested that during the Westphalian A, sedimentation patterns were more

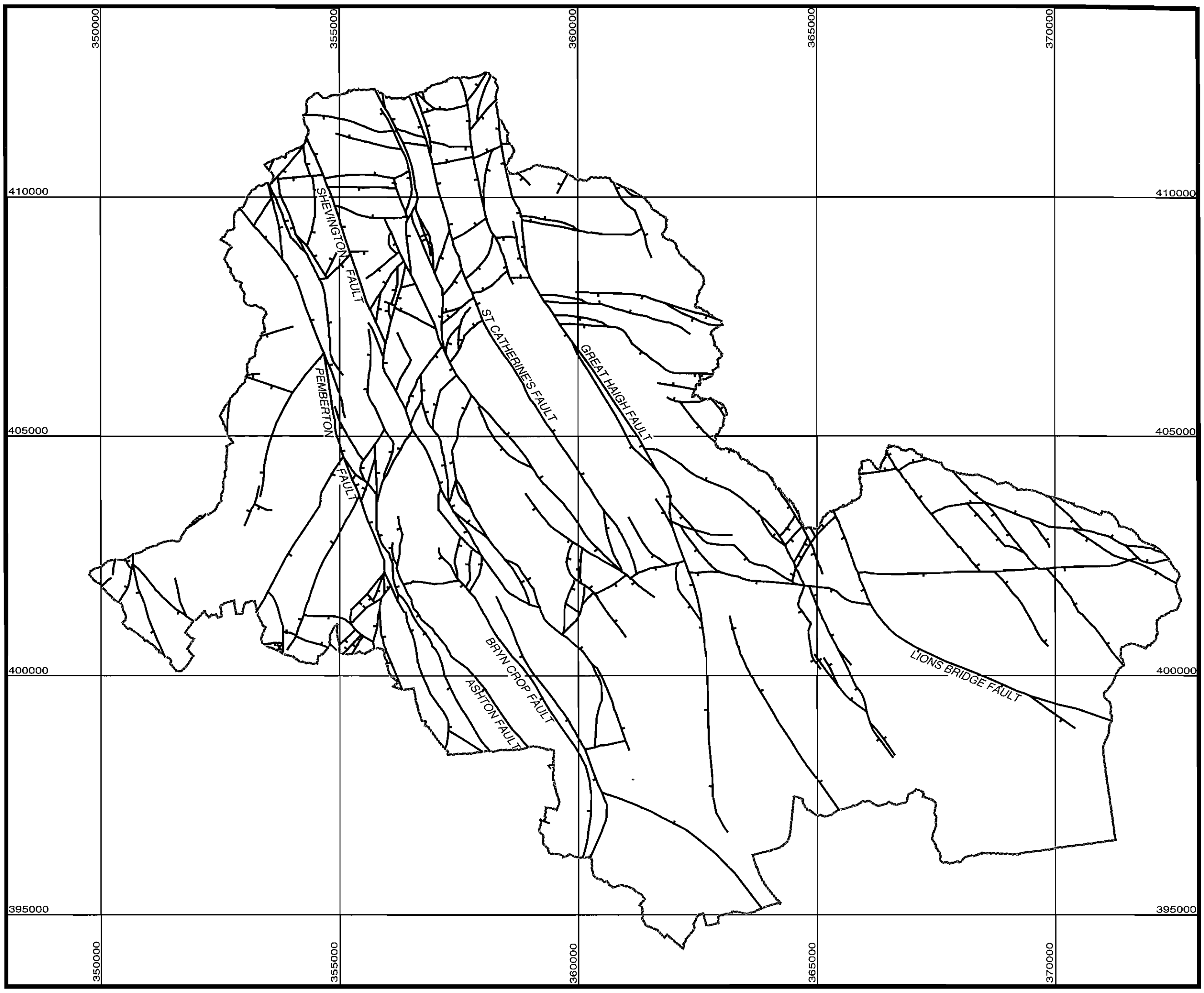


Figure 5 Major faults in the Wigan area.

strongly influenced by syn-sedimentary faulting, but that this influence waned until, during the later Westphalian, consolidation-induced subsidence became the dominant control. Fault control of sedimentation in the Westphalian has not been recognised in the Wigan area. However, control of sedimentation patterns attributed to differential subsidence is commonly recognised. For instance, the distribution of strata overlying major sandstone bodies (e.g. major distributary channels) is often governed by the presence of the underlying sandstone.

Variscan structures (post Westphalian C — Pre Ardwick Formation)

A period of structural upheaval after the deposition of the Coal Measures was followed by regional uplift and erosion prior to deposition of the Permo-Triassic strata. The effects of this period of earth movement, known as the Variscan Orogeny, commenced, probably, in late Westphalian C times and continued until early Permian times. The main mountain building front lay far to the south, in South Wales and Cornwall.

In the north of the Wigan area, pre-Permian uplift and erosion were such that Permo-Triassic strata rest directly on Westphalian A to C strata. In the south of the area, below the ground surface, the apparently conformable Westphalian D, Ardwick Group is preserved, which suggests continuous deposition took place until this time. However, knowledge of this Group is poor and the timing of deformation relative to the deposition of the Group is uncertain. It is estimated that between 500 and 1500 m of Variscan uplift and erosion occurred in the Wigan area (Fraser et al., 1990).

Permo-Triassic structures

Sedimentation recommenced in the early Permian with a change to a new tectonic regime marked by widespread regional subsidence. Pronounced thickness variations in the Collyhurst Sandstone Formation in the Wigan area have been used as evidence of syn-sedimentary faulting during the early Permian (Jones et al. 1938). On the Great Haigh Fault, up to 100 m of throw occurred during the Early Permian. However, Poole and Whiteman (1955) interpreted variation in the Manchester area to be due to burial of a pronounced pre-Collyhurst Sandstone Formation topographic surface, with little or no control by faulting.

Post Triassic structures

The last deformation event comprised a major phase of east-west extensional faulting. This was responsible for

A A'

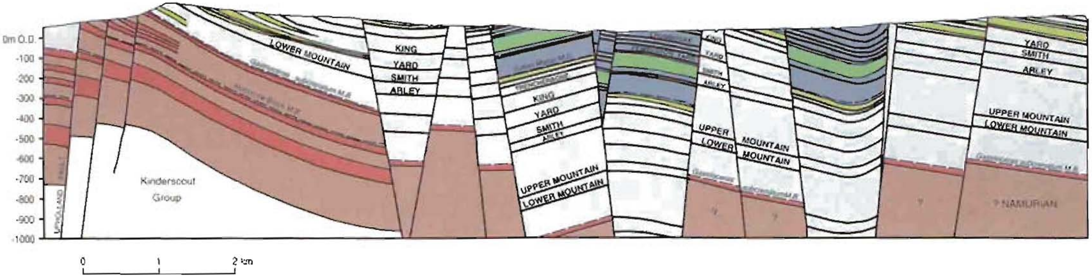


Figure 6 Graben structure in the bedrock below the Wigan area.

the 'normal' faulting which disrupts the strata of the Wigan area and causes their complex outcrop pattern. The most obvious large scale structure is the north-trending 'Wigan graben', bounded to the west by the Pemberton Fault and to the east by the Great Haigh Fault. Large, opposing downthrows on these faults have the effect of juxtaposing younger rocks in the graben with older rocks to either side. In the north of the area Westphalian B rocks are juxtaposed against Westphalian A, while in the south the overlying Permo-Triassic is down-thrown into contact with the Westphalian. This graben structure is illustrated in Figure 6.

In the south of the area abundant shaft, borehole and underground evidence allows accurate determinations of post-Permian fault throws. For instance the Great Haigh Fault displaces the base of the Manchester Marl Formation by some 220 m. The Carboniferous strata in the same area are displaced by 320 m, the remaining 100 m of throw being accommodated by the variation in thickness of the Collyhurst Sandstone.

North of the outcrop of the Permo-Triassic, only the total cumulative throw on faults can be determined from the offset of Carboniferous strata. It is probable that most of the current 'normal' offset is the result of post-Triassic extension.

Commencing around 60 million years ago, gentle uplift and erosion of the Pennine Anticline during the Cenozoic led to the present day location of strata. The Wigan area is located on the flanks of this anticline. Uplift and erosion, probably amounting to a few 100's of metres, has been greater in the north of the area, resulting in the complete erosion of the Permo-Triassic strata, while in the south a steadily thickening wedge of Permo-Triassic rocks dipping southwards into the Cheshire Basin is preserved.

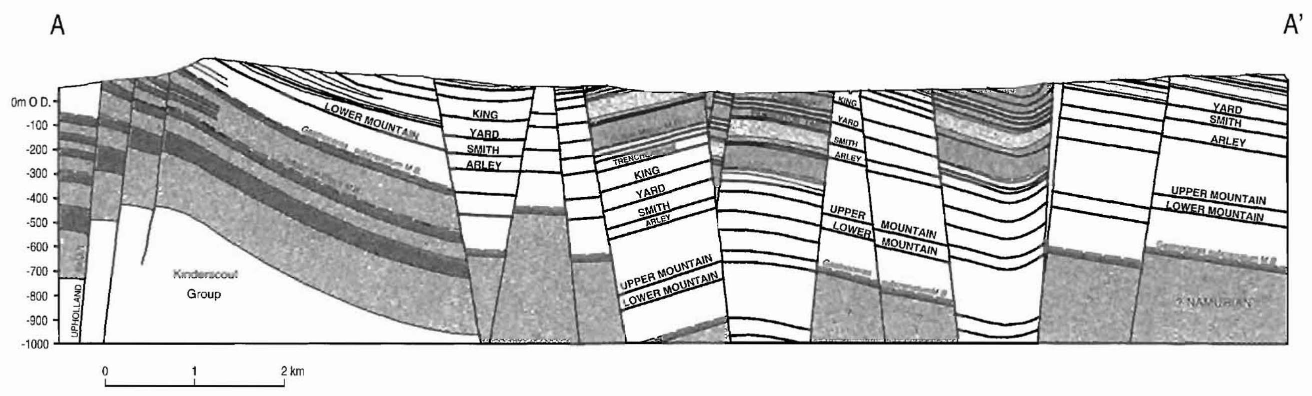


Figure 6 Graben structure in the bedrock below the Wigan area.

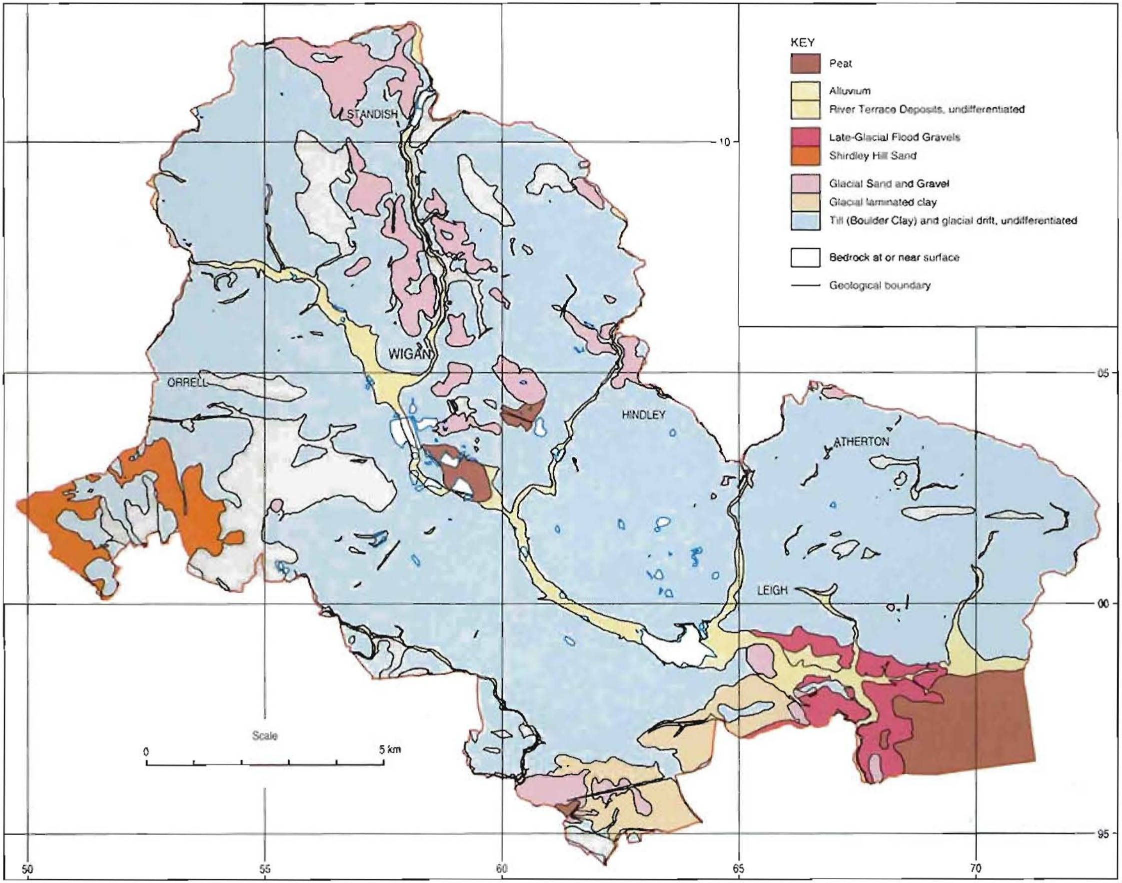


Figure 7 Disposition of superficial deposits in the Wigan area (inset from drift map).

8 Superficial geology

INTRODUCTION

The disposition of superficial deposits is illustrated in Figure 7 and shown in detail on Map 3. The boundaries of the superficial deposits have been digitised from the 1:10560 scale maps produced during the geological resurvey in the 1930's. Therefore, Map 3, the 1:25 000 scale superficial geology map, is more detailed than the published 1:50 000 scale maps. Limited revision of the superficial geology was undertaken during this study, based predominantly on information derived from borehole records. Geological boundaries have been revised only where boreholes have shown the existing bedrock/ superficial boundary to be in error. The sites of boreholes which record a surface lithology different from that on the existing map within the superficial-covered area are shown on Map 3.

Much of the district is covered by Glacial or Post Glacial deposits. Open sections are few and the ground is often largely built over or modified by the activities of man. Only natural superficial deposits are considered in this Chapter, the interaction between these and man-made deposits is discussed in Chapter 12. The deposition of superficial deposits has caused the present day topography to be generally more subdued than the underlying rockhead surface (Figures 8 and 9). An appreciation of the variations within the superficial deposits and of their relationships to the underlying bedrock is important when considering development, in terms of ground conditions for building and for the environmental implications of waste disposal or spillage.

SUMMARY OF QUATERNARY HISTORY

It is generally accepted that the bedrock surface was largely fashioned during a time of intense tropical weathering and denudation in the Tertiary period, (Belbin,

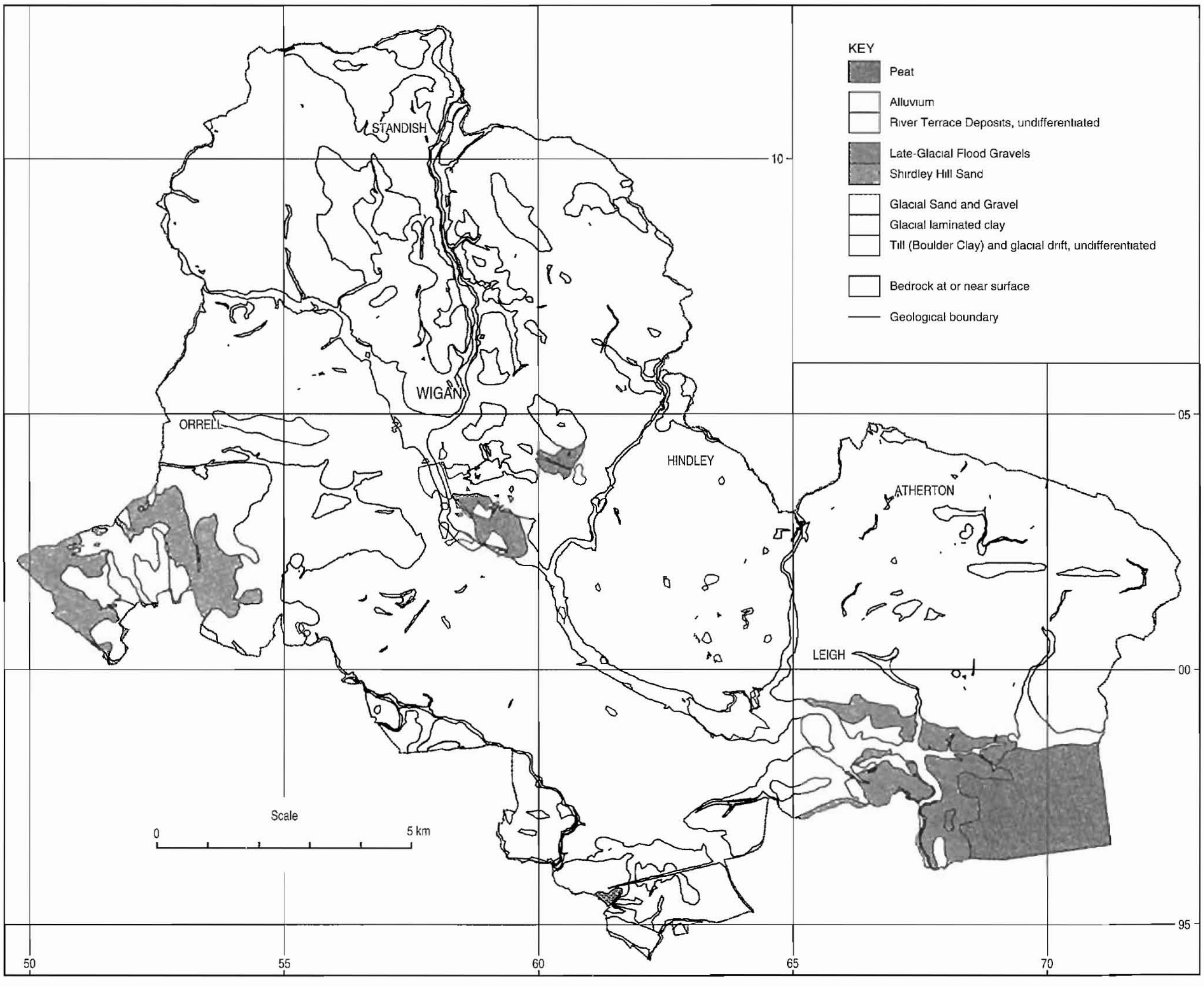


Figure 7 Disposition of superficial deposits in the Wigan area (inset from drift map).

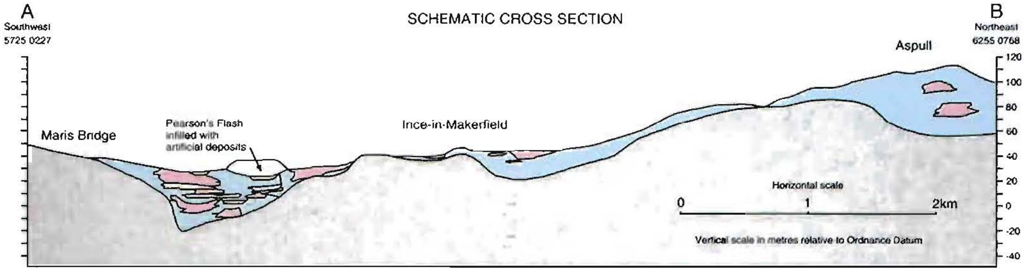


Figure 8 Underlying rockhead surface in the Wigan area.

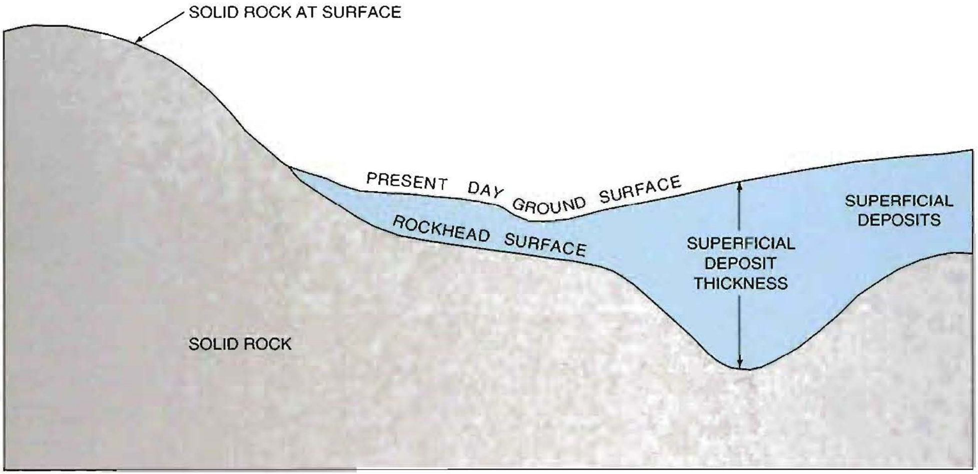


Figure 9 Cross section of buried river channel.

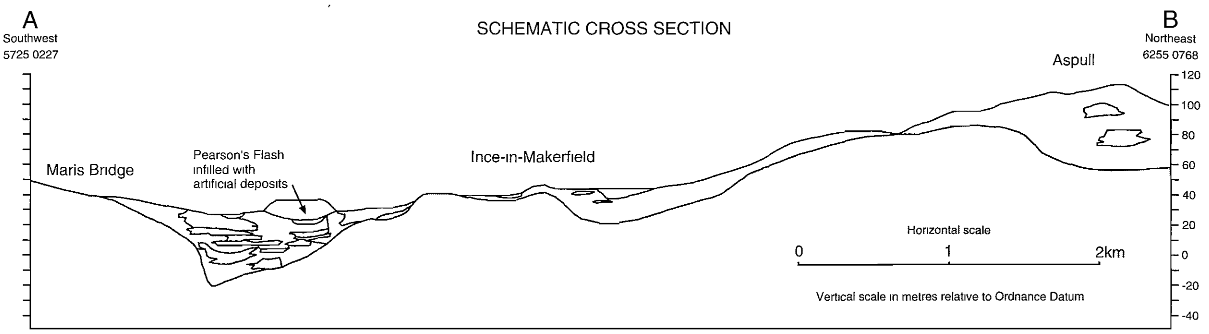


Figure 8 Underlying rockhead surface in the Wigan area.

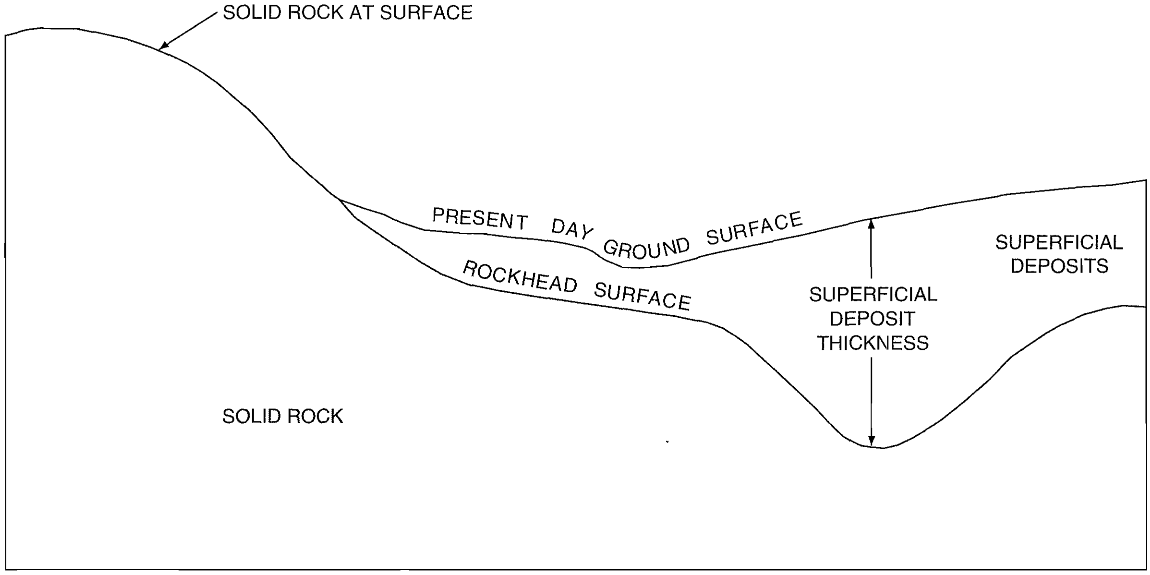


Figure 9 Cross section of buried river channel.

1985) and that the present day topography is largely the result of the deposition of glacial materials during the Pleistocene. The area has been glaciated at least three times, although there is uncertainty as to the number and extent of events because the evidence for earlier phases has been obliterated by more recent episodes. The most significant glaciation in terms of shaping the landscape was the last, the Devensian. The land was exposed to severe frost attack due to the intense cold which preceded the ice sheet as it emerged from the Lake District and Southern Scotland. Shattered and weathered rock, extending to depths locally exceeding 5m below rockhead, are seen in boreholes penetrating through superficial deposits into the bedrock beneath. Consequently, it may be extremely difficult to distinguish weathered rockhead from overlying superficial deposits when logging cored boreholes. The Tertiary topography, now periglacially weathered, was then modified by the erosive effect of the ice-sheet moving over the area during its active advance. The Permo-Triassic and Carboniferous mudstones and siltstones were eroded more than the sandstones, so that glaciation accentuated lithological variation across the area.

The decay of the ice-sheet, between 16000–14000 BP, released large volumes of meltwater (Thomas, 1985). A pattern of sub-parallel streams evolved, influenced by both the geological structure of the ground and the configuration of the retreating ice-sheet. The streams formed a series of, generally, NW–SE aligned valleys which were subsequently infilled by large volumes of supra-glacial material which were released into the meltwater as the ice melted. The setting and possible mode of evolution of these are discussed by Howell (1973).

A series of regionally significant, large, late-glacial, meltwater channels have been recognized on the northern margin of the study area, southwards from an arc between Chorley and Bolton. These features, commonly termed 'glacial overflow channels', may have been formed by the erosional effects of meltwater flowing at and below the edge of the waning ice sheet (Cunningham, 1972). As the ice south of Bolton stagnated and downwasted, the meltwater escaped via the Douglas valley to Wigan and thence, via the Glaze valley, into the proto-Mersey. During the final stage a more direct westerly route became available so that the meltwater followed the Yarrow and finally the Douglas through the Parbold Gap. In its lower reaches the Douglas is constrained to follow such a meltwater channel, swinging from SW to SE as it enters the channel in Wigan [SD 580050] (Williams, 1977).

Initial deposition was from the release of sediment in water, but later vast volumes of unstratified sediments were released though sub-glacial and en-glacial melting of the ice. This material was commonly reworked and redeposited as a series of sands and gravels.

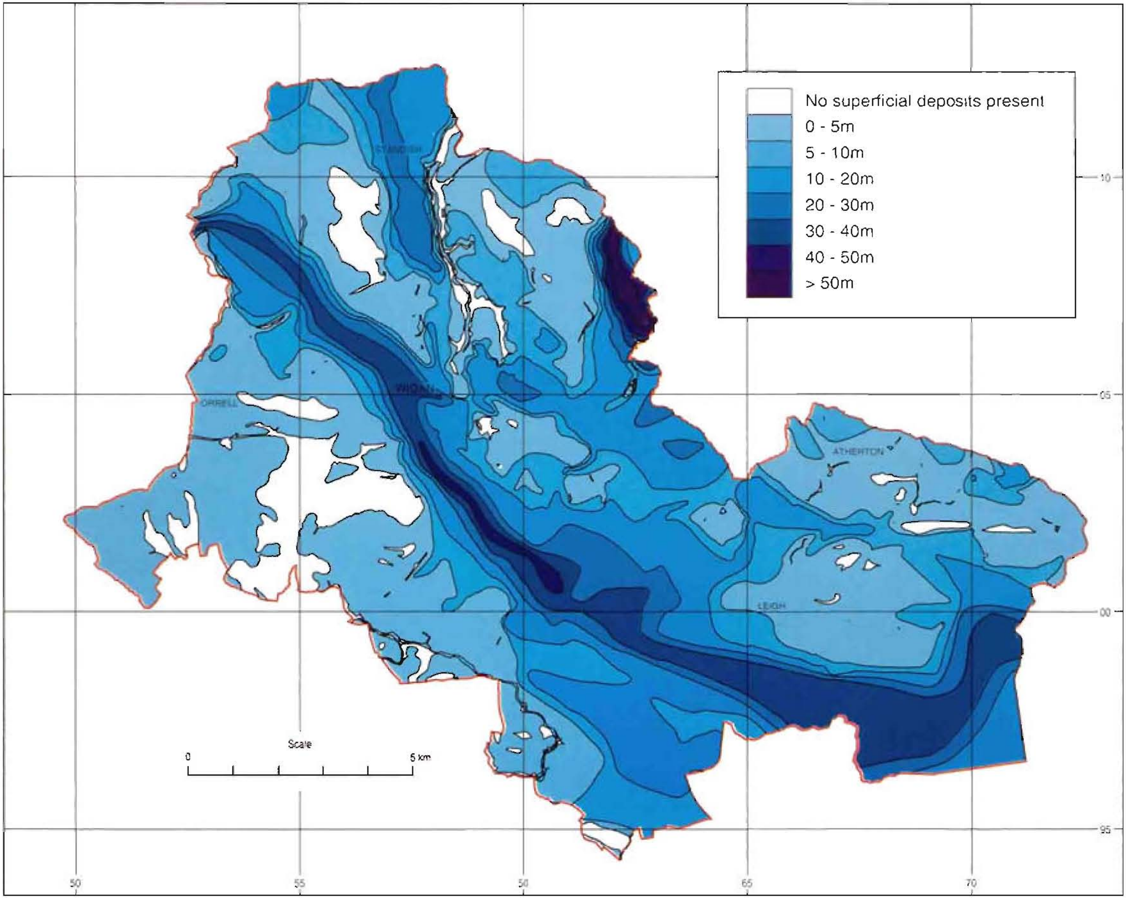


Figure 10 Superficial deposit thickness contours.

SUPERFICIAL DEPOSIT THICKNESS AND ROCKHEAD TOPOGRAPHY

Figure 10 shows the thickness of natural superficial deposits in the Wigan Metropolitan Borough. Over almost half the area of the Borough the deposits are less than five metres thick, but locally drift-filled channels attain thicknesses exceeding 50 m. The major NW-SE channel, roughly aligned between Shevington and Pennington, is offset from the present day river course in the area of Scotsman's Flash (Figure 8). Borehole information has enabled details of its course to be refined. A deep drift-filled channel has also been identified at the edge of the Borough to the east of Aspull.

DETAILS OF SUPERFICIAL DEPOSITS

Till

Till (boulder clay) is the predominant superficial deposit exposed at the surface. Until the latter half of this century the glacial sequence in the Lancashire Plain was considered to consist of an Upper Boulder Clay and a Lower Boulder Clay separated by Middle Sands as described in the Geological Survey Memoir (Jones et al., 1938). Evidence from boreholes caused Cresswell (1964) to doubt the validity of this three layer succession. It was further challenged by Johnson (1971), who recognised a general pattern of a single till overlying sands and gravels within which he defined areas of multiple stratigraphical successions.

Till can be classified into a number of different types according to the manner in which it was deposited from the ice sheet. Longworth (1985) recognised three main types within the Lancashire Plain, but it is likely that till deposited by the melting of stagnant ice (melt-out till) is the dominant type in the Wigan area. Owing to the lack of natural sections and insufficient information recorded in most borehole records no subdivision of the till has been attempted in this study.

Glacial Sand and Gravel

The major surface exposure of glacial sand and gravel is a N–S belt in the northern part of the area, although other isolated patches are also present. Jones et al. (1938) recognized an extensive area of 'Middle Sands' between their Upper and Lower Boulder Clay. Although such a clear cut division is not accepted today the presence of large quantities of sand and gravel within the glacial

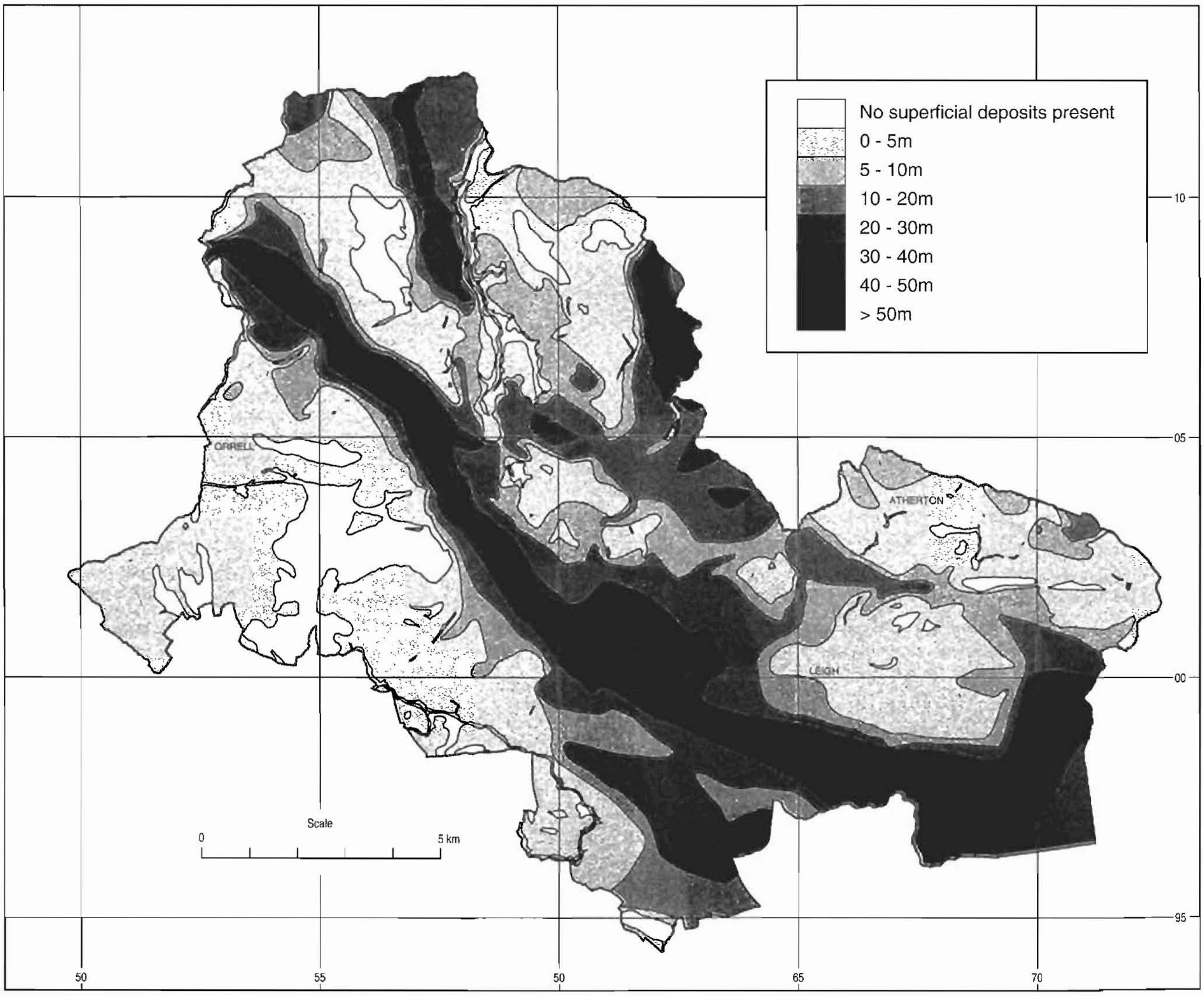


Figure 10 Superficial deposit thickness contours.

deposits is undisputed. Exposures formerly seen in quarries, notably around Standish, displayed current bedding and were associated with bedded silts and clays.

Glacial Laminated Clay

Glacial laminated clay is not currently seen in natural sections in the area and generally can be detected only from boreholes. It consists of clays and silts often with thin laminae of sand and fine silty sand. The dominant colour is grey to white but it also occurs in shades of brown. The grey beds can be traced until their thickness is no more than 150 mm and almost everywhere their limit is unmarked by any feature or change in character of the surface. Borehole logs found during the study have shown the extent of glacial laminated clay, particularly within till at shallow depths, to be greater than was previously thought.

Late Glacial Flood Gravels

Immediately south of Leigh sands with ochreous gravel extend up the broad, shallow valley of Glaze Brook towards the Flash. They are well defined along their edges which border the present alluvium but thin onto drift at their outer margins with little or no feature. They form part of the great spread of flood gravels which constitute the Manchester Plain.

Shirdley Hill Sand

The Shirdley Hill Sand occur in the west of the area on the western slopes of the Bispham Hall–Billinge ridge. It represents the easternmost occurrence of a windblown deposit which covers the undulating West Lancashire Plain. Its average thickness varies between 2.5 and 3.5 m and it is divisible into an upper 'white' sand and a lower 'brown' sand which is olive grey and brown with peaty layers.

Prior to the cultivation of the district the Shirdley Hill Sand supported a thin development of peat which has been worked in with the underlying sand during cultivation so that the resulting peaty sandy loams form 'black' topsoils which mark the outcrop of the sand. The edge of the sand is extremely difficult to map in natural exposures as it feathers out on to the till. Mapping its extent is no easier where it has been worked for use in glassmaking (section 10 Mineral Resources); after the replacement of the original topsoil only a slight variation in level marks the transition from worked to unworked areas.

The Shirdley Hill Sand is, generally, moderately to well sorted, fine sand with mainly rounded and sub-rounded quartz grains. A detailed study of the Sand by Wilson et al. (1981) concluded that it was an aeolian deposit, derived almost exclusively from fluvio-glacial deposits, and a true periglacial cover sand of Late Devensian (Zone III) age analogous to the widespread cover sands of central Europe.

Peat

Following the deposition of the Shirdley Hill Sand, peat accumulated over part of the area and is present today in the southeast of the district at Chat Moss. At higher levels peat has developed on the watershed of the Glaze Brook and Douglas drainages at Ince Moss.

Alluvium

Alluvium is present as thin spreads along the valleys of the river Douglas and its tributaries and in small discontinuous strips in other streams and hollows within the area. For the most part it consists of sand and gravel with some grey, silty and organic clays.

9 Hydrology and hydrogeology

INTRODUCTION

Water will play an important role in the further development of the Wigan Metropolitan Area. Although much of the supply for Wigan itself is from surface water sources to the north, groundwater from the Sherwood Sandstone provides a significant part of the municipal supply enjoyed locally and outside the Wigan area. Therefore, development in areas where this aquifer is vulnerable to contamination must be closely monitored. Mine closures in the area may lead to rapidly rising water levels within the Coal Measures and the threat of highly acidic and mineralised groundwater polluting rivers and streams. The legacy of mining has also produced eccentric and convoluted subsurface drainage patterns, allowing mixing between sandstone units. A good understanding of the conditions of both surface and groundwater in the area will enable development to take place that will allow the maximum use of these precious resources.

SURFACE WATER

The drainage pattern

The Wigan Metropolitan Area is drained by two river networks. The River Douglas and its tributaries drain the north-east of the area, while to the south the area is drained by tributaries of the Mersey network. The River Douglas originates outside the northern boundary of the Wigan area and flows southward through the centre of Wigan. South of the town centre, the river turns sharply and flows in a north-westerly direction towards Shevington, where it passes out of the study area. The southern and eastern parts of the Wigan area are drained by Glaze Brook, a tributary of the River Mersey. Glaze Brook is created by the confluence of two tributary networks south of Leigh; Moss Brook and Pennington Brook; the river then continues southward and flows out of the study area to the west of Culcheth.

The catchment boundary between the two river networks curves from an east-west direction in the west of the area, south of Wigan, to run north-south between Hindley and Ince-in-Makerfield. The hydrometric area boundaries shown on Map 4 are intended to represent an approximation to the topographic catchment of the surface water system and may not represent groundwater catchment areas or places where the surface water catchment may have been modified by artificial drainage or engineering works.

There is one river gauging station within the study area, located at [SD 5870 0611] on the River Douglas. The river hydrograph (Figure 11) is complex. Industrial, agricultural and municipal abstractions from the river plus rainfall events and industrial discharges to the river cause short term fluctuations on the hydrograph which are set against a smoother flow profile buffered by the upstream Rivington Reservoir system. However, in general, flows are highest in December and January (greater than 1.8 cubic meters per second) and lowest from May to July (approximately 0.7 cubic metres per second). The 30 day moving average shows a smoothed long term average that compensates for erratic daily events.

The Leeds and Liverpool Canal cuts across the Wigan area. The main route of the Canal follows roughly the route of the River Douglas, with a large deviation caused by a set of locks to the north of Ince-in-Makerfield. Water is supplied from the river to the Canal at Scholes and Gathurst Weirs. The Bridgewater Canal and the Leeds and Liverpool Canal join in the centre of Leigh near Bedford Basin.

Past mining activities have affected the surface drainage pattern. In places, subsidence caused by mining has produced large shallow depressions. Their subsequent infilling by water has formed large lakes known locally as 'flashes'.

Flooding

The areas most at risk from flooding are along the flood plain of the River Douglas. Extreme rainfall events can increase the volume of water sufficiently to enable water to flow over the banks causing flooding (Anon, 1966). Consequently, several flood defence schemes are in place along the length of the river. The areas marked on Map 4 as being at risk from flooding are defined as the area of maximum known flooding, or the area defended by a flood defence scheme, whichever is greater. Therefore, it is possible that some areas marked as at risk from flooding might have been made less vulnerable by improved defense.

Chat Moss, to the south-east of the area, was originally a large area of marshland. Thick peat deposits and till impeded natural drainage and confined the underlying Sherwood Sandstone aquifer rendering it in some places artesian. The value of the land for farming, however, led to the construction and implementation of an extensive drainage network. Large drainage ditches flow into the various tributaries of Glaze Brook.

Surface water chemistry

The quality of surface water around Wigan is linked to the legacy of industry and mining in the area. Many of the surface waters are polluted and support little aquatic life. The National Rivers Authority (NRA) regularly monitors water from the rivers and canals and produces maps illustrating the results. The information shown on Map 4 was taken from the NRA's most recent survey published in 1990. The surface waters are classified into four bands (Table 1) using several biochemical criteria including: dissolved oxygen content, the biochemical oxygen demand, and the concentration of ammonia.

The rivers and canals within the Wigan area are generally classified as containing water of "poor" or "bad" quality, with the exception of the River Douglas and some smaller tributaries of the two river networks which are considered "fair". Industrial discharges to the rivers and the legacy of mining are mainly responsible for the poor quality water. The recent closure of local coal mines and

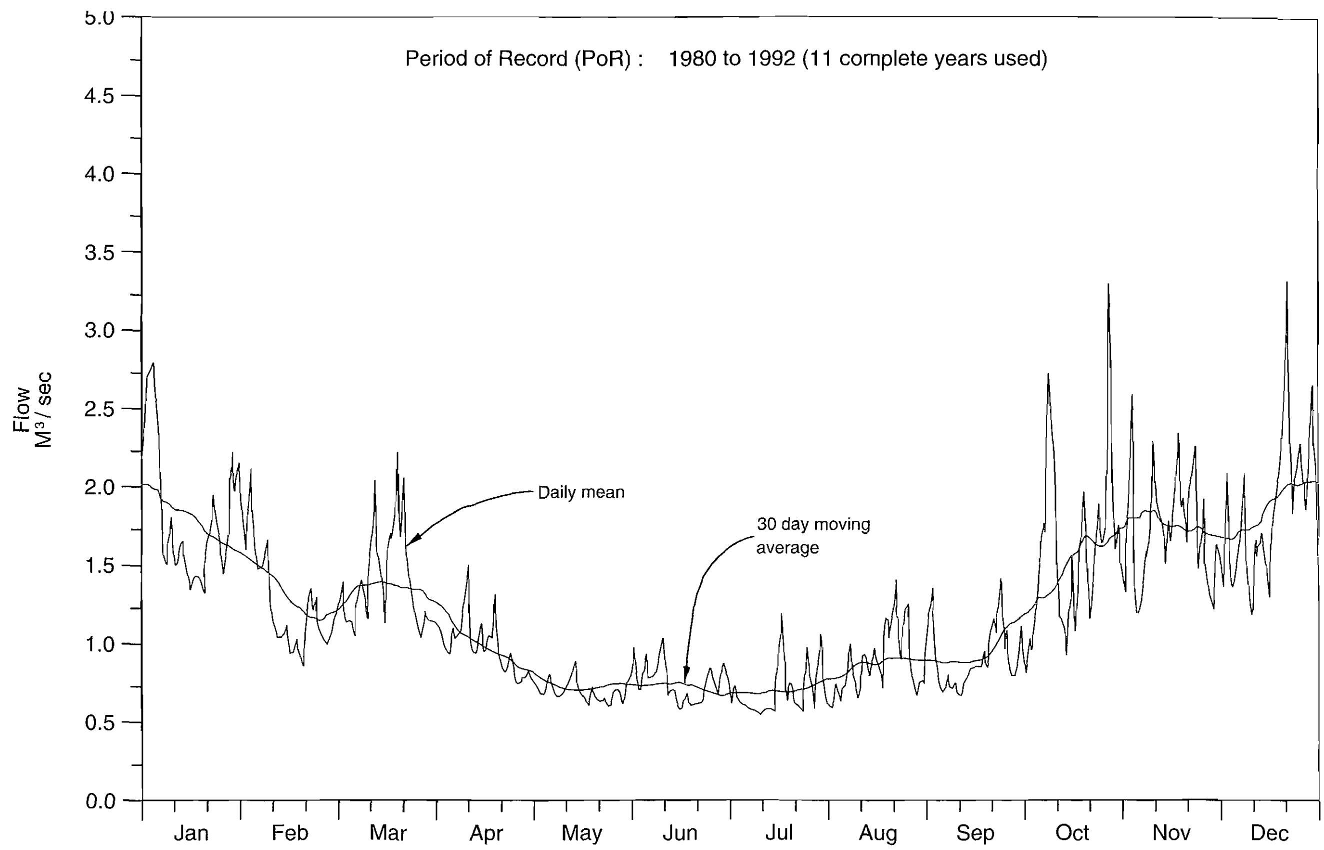


Figure 11 River hydrograph for gauging station at SD 5870 0611 on the River Douglas.

the cessation of pumping from the mine workings could further reduce the quality of surface water. Mine waters tend to be more acidic and rich in dissolved iron. If this water discharges into a river or stream, iron hydroxides can be deposited, coating the river bed and adversely affecting plants and animals. The effect of mine closure will be discussed more fully in a later section of this Chapter.

Table 1 Classification of surface water (National Rivers Authority, 1990 Survey).

Class	*Description*
1 Good	Water of high quality suitable for potable supply abstractions: game or other high class fisheries; high amenity value.
2 Fair	Waters suitable for potable supply after advanced treatment; supporting reasonably good coarse fisheries; moderate amenity value.
3 Poor	Waters which are polluted to an extent that fish are absent or only sporadically present; may be used for low grade industrial abstraction purposes; considerable potential for further use if cleaned up
4 Bad	Waters which are grossly polluted and likely to cause a nuisance.

GROUNDWATER

Much of the Wigan area is underlain by Coal Measures rocks of Carboniferous age. These strata comprise complex, multi-layered aquifers which have been much modified by past mining activities. Although not normally considered to be a major aquifer, groundwater contained within the Coal Measures has been of considerable historic importance in the industrial development of the area.

The southern section of the area is underlain by Permo-Triassic sandstones, of which the Sherwood Sandstone is a major aquifer of regional importance. This aquifer has been exploited for over a century for industrial and public supply, because of its favourable aquifer properties and good quality water. Superficial deposits, composed predominantly of clay-rich material, have little groundwater resource potential but play an important role in controlling recharge.

Hydrogeological characteristics

A brief summary of the hydrogeological properties of the various lithological units present in the Wigan area is presented in Table 2.

The two main aquifers are the Sherwood Sandstone and the sandstone units within the Carboniferous, Coal Measures. Other units of hydraulic significance are the Collyhurst Sandstone and the Manchester Marl. The Collyhurst Sandstone is virtually unexploited in the Wigan area. This is probably due to its deep confinement below

Table 2 Summary of the hydrogeological properties of the lithological units in the Wigan area.

Hydrogeological Unit	*Character*	*Hydrogeological characteristics*
Sand and Gravel	Minor aquifer	Minor aquifers within superficial deposits give shallow perched water tables or increase recharge to underlying aquifers.
Till	Aquitard/aquiclude	Covers much of the area, inhibits recharge and in places confines the underlying aquifers
Sherwood Sandstone	Major aquifer	High permeability. Groundwater flow is through fractures and pore spaces and is generally restricted to the upper 200 m.
Manchester Marl	Aquitard/aquiclude	Forms a low permeability layer which confines the Collyhurst Sandstone and inhibits hydraulic contact between the Collyhurst and Sherwood sandstones.
Collyhurst Sandstone	Minor aquifer	A thin friable sandstone of high permeability not generally exploited due to its deep confinement and narrow outcrop.
Coal Measures	Aquifer	Sandstones within the Coal Measures can be locally important aquifers. They are generally well cemented and groundwater flow is through fractures. Numerous faults dissect the sandstone units into small blocks. Mineworkings, if present may provide highly transmissive conduits for groundwater not naturally present in strata including those normally regarded as impermeable.

the productive Sherwood Sandstone aquifer and its narrow outcrop. It is possible that the water quality within the Collyhurst Sandstone is poor due to contact with Carboniferous groundwater. The Manchester Marl acts as an aquitard, preventing leakage between the Collyhurst and Sherwood Sandstones.

Carboniferous — Coal Measures

The Coal Measures form a complex multi-layered aquifer. Argillaceous strata predominate with occasional interbedded thicker sandstone horizons. The former act as aquicludes or aquitards, isolating the sandstone horizons, which effectively act as separate aquifers. Sandstone units known to act as aquifers include the Pemberton, Ravenhead, Trencherbone and Old Lawrence Rocks and the Crutchman Sandstone. The Coal Measures are extensively folded and faulted which, under natural conditions, creates isolated blocks of aquifer and inhibits lateral and vertical hydraulic continuity. This situation will have been greatly modified over much of the Wigan area by the legacy of past mining activities, directly by the construction of shafts and galleries and indirectly by the effects of subsidence. Subsidence will have created vertical fractures cutting across and connecting previously separate aquifer horizons.

The sandstone horizons are generally well cemented and possess little primary (inter-granular) permeability or porosity. Groundwater storage and transport is largely dependent on fractures in the otherwise weakly permeable sandstones. In addition, the sandstones may be limited in lateral extent either due to changes in thickness or faulting which reduces their value as aquifers. Borehole and well yields are dependent not only on penetrating a productive horizon but also upon encountering fractures of an adequate size and lateral extent. Yields are in consequence highly variable. Yields from boreholes up to 300 mm in diameter generally range from 5 to 10 l/s, whilst yields from large diameter mine shafts may exceed 20 l/s. Although not specifically reported in the area, initial yields may decline in response to long-term pumping due to depletion of storage in horizons which, lacking an extensive outcrop, receive only limited recharge.

The Sherwood Sandstone

The Sherwood Sandstone is currently the most heavily exploited aquifer in the Wigan Metropolitan Borough. Within the study area, the Chester Pebble Beds have been identified as a distinct formation within the otherwise undifferentiated Sherwood Sandstone. However, for the purposes of groundwater movement, the Sherwood Sandstone will be treated as one aquifer. The lower boundary of the Sherwood Sandstone is defined as the top of the Manchester Marl. The Manchester Marl acts as an aquitard, preventing direct hydraulic continuity between the Sherwood Sandstone above and the deeper, confined, Collyhurst Sandstone. The Sherwood Sandstone thickens down dip towards the south-east, away from the exposed boundary and the underlying Manchester Marl, reaching a thickness of about 500 m beneath Chat Moss, and continues to thicken to the south, outside the Wigan area. In practice, as a result of decreasing permeability with depth, groundwater flow is usually restricted to the upper 200 m of the Sherwood Sandstone.

Pumping tests indicate transmissivity to range from 40–1400 m^2/d with the majority of tests giving values of between 100 and 300 m^2/d. Borehole yields are normally high, with some large diameter production boreholes yielding in excess of 100 l/s. The aquifer is generally unconfined, although thick drift deposits can act locally as confining layers.

Groundwater movement within the aquifer is dependent not only on inter-granular permeability but also the presence of fractures. Laboratory measurements of inter-granular horizontal permeability give typical values of about 0.5 m/d (Lovelock, 1977; Campbell, 1982) and porosity measurements of between 20 and 30%. Most boreholes in the area penetrate approximately 100 m of saturated sandstone, therefore, if only inter-granular flow was occurring the observed transmissivity should be only 50 m^2/d. Transmissivity values, calculated from pumping tests (see above) and numerical modelling (Anon, 1981a) are generally much greater than 50 m^2/d, suggesting a significant contribution from fracture flow. Detailed packer testing and fracture analysis at Kenyon Junction [SJ 6481 9655] indicated that about 70% of the flow into the borehole was from fractures (Campbell, 1982). However, at greater depths, the contribution of flow from fractures decreases. Therefore, for most practical purposes, the aquifer is considered to be less than 200 m thick. Laboratory measurements of permeability have indicated that unfissured samples of Sherwood Sandstone are anisotropic, with higher permeability parallel to the bedding plane (Bow et al., 1970). The observed anisotropy has a significant effect on groundwater flow both at a regional and a local scale.

The Wigan Metropolitan area is dissected by many faults. Where the throw of these faults is small, the hydraulic continuity within the Sherwood Sandstone can be maintained, depending on the permeability of the fault zone. The fracturing associated with faults can actually increase the permeability of the sandstone by allowing a greater component of fracture flow. However, permeability can be reduced when impermeable fills are associated with faulting. Faults with large displacements, for example, the Winwick fault, can also reduce the groundwater movement within the aquifer by up-throwing the less permeable Manchester Marl or Carboniferous strata against the Sherwood Sandstone. The Winwick fault is believed to act as a major groundwater barrier in the area, dividing the Sherwood Sandstone aquifer into two blocks along a north-south line from Ashton-in-Makerfield, through Golborne to Winwick.

Superficial deposits

The most widespread superficial deposit is glacial till which blankets the bedrock over much of the Wigan area. The clay-rich component of the till possesses considerable porosity but, due to its very fine-grained nature, negligible permeability. Therefore, it may be regarded as effectively impermeable. The till does confine groundwater in the underlying Coal Measures and Sherwood Sandstones in some low lying parts of the area.

Glacial sands and gravels are both contained within the till as lens-shaped bodies of limited lateral extent and as thin sheets overlying the till. These sands and gravels are often loose and generally contain groundwater particularly at low elevations. Their limited thickness and lateral extent preclude their use for major abstractions but they have provided more modest quantities, from shallow wells, mainly for domestic and agricultural use. Groundwater within the glacial sands and gravels often forms perched aquifers with water levels close to ground level (Figure 12). Made ground, often consisting of mining waste, can also contain ground-

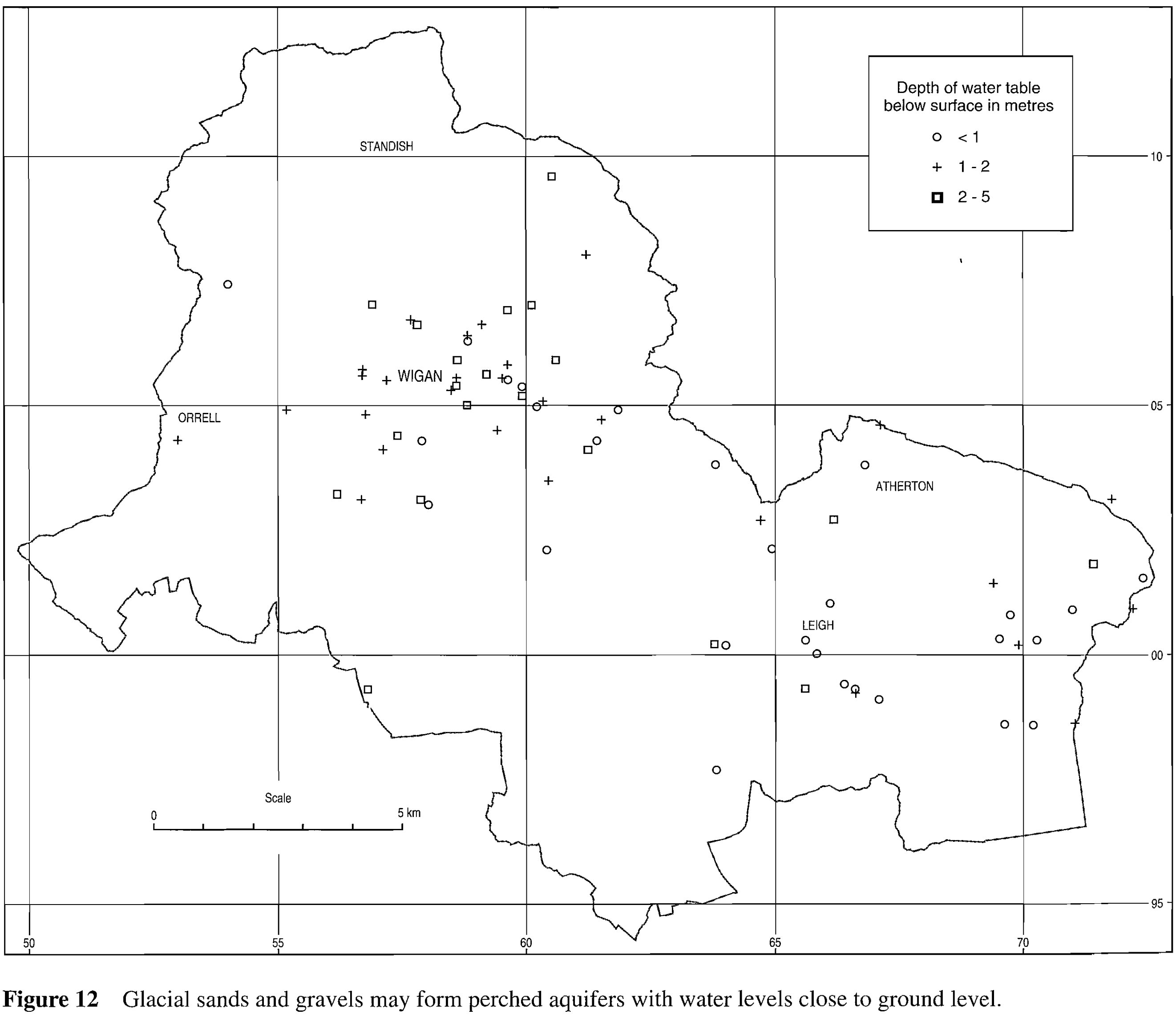


Figure 12 Glacial sands and gravels may form perched aquifers with water levels close to ground level.

water where it overlies low permeability till. Ince Moss, for example, contains many perched aquifers above the underlying till. There are also considerable thicknesses of water saturated peat in the Chat Moss area where surface drainage ditches are required to maintain water levels below the ground surface.

AQUIFER RECHARGE

The Wigan area experiences a temperate maritime climate, with cool, wet winters, and warm, often wet, summers. Averaged monthly climatic data, (for the period between 1961 to 1992), for the Wigan area, provided from the Meteorological Office MORECS system, are presented in Figure 13. During the winter months, when precipitation is high and losses due to evapotranspiration are low, there can be an excess of precipitation called *effective rainfall.* This excess rainfall provides the main recharge to the aquifers. However, where an aquifer is overlain by relatively impermeable drift deposits, a significant proportion of the effective rainfall will flow laterally through the soil horizons or be intercepted by field drainage systems. Therefore, significant recharge to the aquifers will only occur where the drift deposits are thin, absent, or moderately permeable. The drift deposits are quite extensive within the Wigan area but by studying the drift thickness and the chemistry of the groundwater, two principal recharge areas to the Sherwood Sandstone have been identified (Anon, 1981a). One is along the south west Metropolitan boundary to the south-west of Ashton-in-Makerfield and Golborne, and the other lies to the east of Leigh.

Recharge can also occur as upward leakage from the Collyhurst Sandstone and laterally from the Carboniferous Coal Measures. An hydraulic gradient towards the Sherwood Sandstone has developed within the groundwater system due to the aquifer's low water-levels. Therefore, upward leakage through the Manchester Marl from the Collyhurst Sandstone can be induced, particularly along fault lines. Lateral leakage from the Carboniferous Coal Measures is possible along certain fault lines where the sandstone units within the Coal Measures are in direct contact with the Sherwood Sandstone. It is unlikely that significant transfer of groundwater will occur across the unfaulted boundaries between the Carboniferous and the Sherwood Sandstone, due to the presence of the low permeability Manchester Marl.

Aquifer recharge occurs most rapidly in the superficial deposits where water levels are commonly close to surface. Due to the rapid recharge, water levels respond quickly to the seasonal changes. Highest water levels are recorded in spring before declining through the summer reaching a low in early autumn. However in other aquifers little seasonal response to recharge is observed.

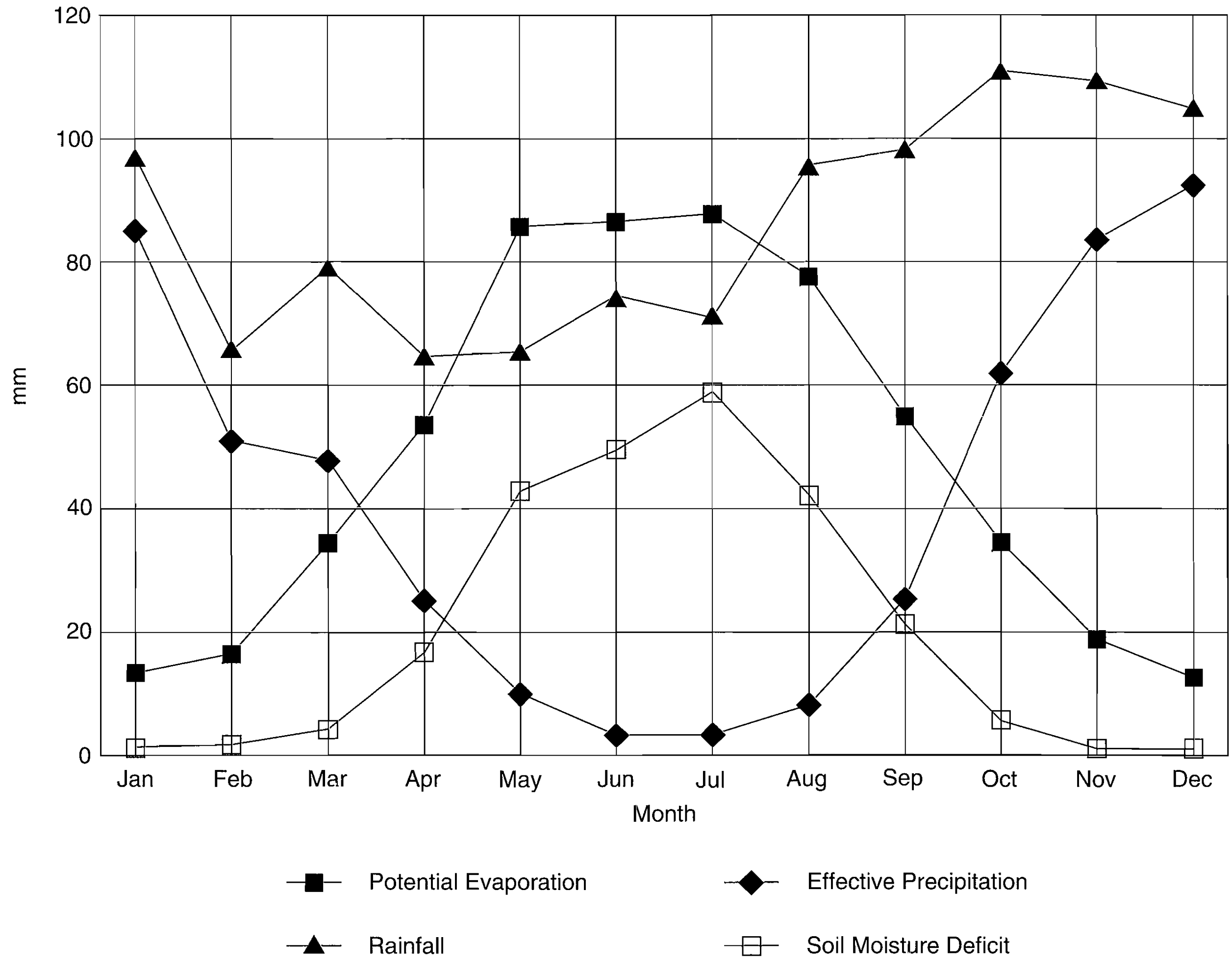


Figure 13 Averaged monthly climatic data (for the period between 1961 to 1992), for the Wigan area, provided from the Meteorological Office MORECS system.

PAST GROUNDWATER ABSTRACTION AND WATER LEVELS

Before the Industrial Revolution

The quantities of groundwater abstracted from the Carboniferous Coal Measures, Sherwood Sandstone and superficial deposits, before the Industrial Revolution in the Wigan area, would have been extremely limited. The aquifers were exploited by shallow hand dug wells and the water utilised for domestic and agricultural purposes. The water table would have represented a subdued reflection of surface topography — even in the Coal Measures where local discontinuities and perched water tables would have been present due to faulting. Recharge would have entered the aquifer in areas where drift was absent, thin or composed of permeable materials and groundwater flow would have been towards areas of lower elevation where springs and seepages would have provided the base flows of rivers and streams. This situation before, during and after the peak of the mining industry is represented in diagrammatic form in Figures 14, 15 and 16.

After the Industrial Revolution

The Industrial Revolution caused a rapid increase in groundwater utilisation, particularly from the Coal Measures, for use by industry and public supply for use by the growing workforce. Coal mining produced the most pronounced changes in the Coal Measures aquifer. Initially, shallow coal seams above the water table were mined. However, as these seams were worked out and the demand for coal grew, successively deeper horizons were worked, and it became necessary to remove the water from the workings by drains or pumps. As the depth of mining increased, so too did the rates of pumping required to drain the workings. In some areas it was advantageous to construct mine drainage adits or soughs.

The soughs, a system of galleries constructed solely for the purpose of providing gravity mine drainage, were generally constructed from the valley bottom at a gentle gradient upwards into the hill side. The local water table was thereby lowered so that the overlying coal seams would be dry, thus permitting mining without the need to pump. The best known and most extensive of these schemes in the area is Gerrards Great Haigh Sough located to the north-east of Wigan. The history and details of the system are described by Ireland (1974) in a hydrogeological study of the Haigh, Aspull and Hindley areas. Great Haigh Sough was the largest system in the area extending for a distance of over 4200 m and rising from an elevation of 40.2 m at its mouth on Yellow Brook to 69.5 m at Aspull Pumping Pit at its eastern extremity

Several other sough systems are known to exist in the Wigan area, for example in the Orrell and Standish areas, although their precise location, extent and current condition are unknown. The available information is shown on Map 4. It is possible that other soughs have been constructed in the area but their location and extent were unrecorded or have been lost. Other soughs outside the area, such as the very extensive Duke of Bridgewater's underground canal to the east, may also influence groundwater conditions within the area. Mine workings extending out from the soughs, were interlinked and provided an ever extending network providing drainage back to the soughs. When it became necessary to mine seams which lay beneath the sough level, it was not uncommon to pump from the base of shafts up to the sough level which was then used to dispose of the deeper mine drainage, for example Aspull Pumping Pit [SD 625 081]. As mine workings extended ever deeper, shafts and horizontal galleries, together with vertical fracturing caused by subsidence, largely destroyed the original multilayered nature of the Coal Measures aquifer.

As a result of the extensive dewatering of the mine networks, groundwater from the Coal Measures was easily and cheaply available. Therefore, the Coal Measures provided most of the water for industrial purposes and public supply within the Wigan area, while the Sherwood Sandstone remained virtually unexploited (Figures 17 and 18). However, water levels in the Sherwood Sandstone were affected by excessive abstraction elsewhere in South Lancashire and were gradually declining (Bow et al. 1969). The overall groundwater situation in the Wigan area in the early 1960's when pumping from coal mines was at its height and water levels in the Coal Measures were at a minimum, is illustrated in Figure 15. At that time it is highly probable that leakage occurred across faulted boundaries from the Sherwood Sandstone to the Coal Measures.

Present conditions

In the early to mid-1960s most coal mines in the Wigan area were closed and mine drainage by pumping had largely ceased except for some deep mines in the south which continued to work until the early 1990s. Abstraction from the Coal Measures for public supply also declined rapidly, as new sources of supply in the Sherwood Sandstone aquifer came into use, and industrial abstraction also declined (Figures 17). Although no contemporary data are available it is probable that water levels within the Coal Measures rose rapidly as mine drainage by pumping ceased, but could never return to the original levels due to the presence of shafts, galleries, soughs and fracturing associated with subsidence. Simultaneously, increased abstraction from the Sherwood Sandstone (Figure 18) caused a considerable lowering of the water table, and created large cones of depression around major public supply pumping stations. Abstraction for industrial use gradually declined after the mid-1960s but is insignificant compared to the massive increase in public supply abstraction; in 1993 the total annual licensed abstraction was over 13 million m^3. An unspecified quantity of water was also abstracted from the Golborne, Bickershaw, and Parsonage Group of mine workings until 1992. Although the mine workings were primarily in the underlying Coal Measures, it is possible that the Sherwood Sandstone was also slightly de-watered. Water levels are likely to have risen rapidly in the Coal Measures after the pumping stopped, and possibly leaked through the mineworkings into the Sherwood Sandstone.

The regional recovery of water levels within the Coal Measures has lead to the lateral movement of water from the Coal Measures into the Sherwood Sandstone aquifer. This could, potentially, contaminate the Sherwood Sandstone aquifer due to the lower water quality in the Coal Measures

The direction of groundwater flow within the Sherwood Sandstone is dominated by current abstraction patterns. The regional movement of water was probably to the south before the aquifer was heavily developed, (Taylor, 1957; Anon, 1963), with localised cones of depression around pumping boreholes. As industrial abstraction increased, water levels in the aquifer generally declined especially to the south of the area around the Mersey and to the east of the Manchester area. Interpretation of the limited water-

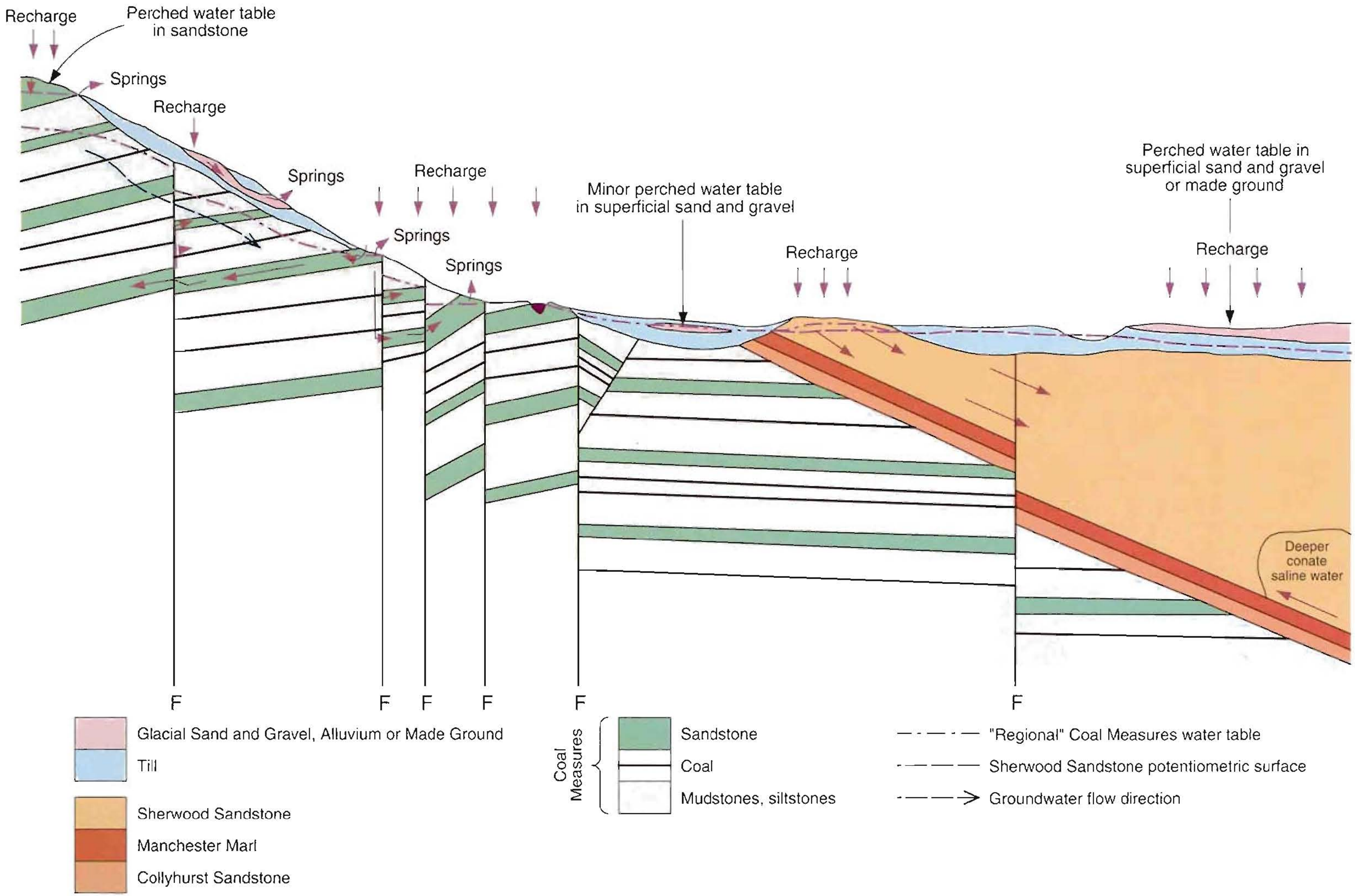


Figure 14 Groundwater abstraction and water levels before minin

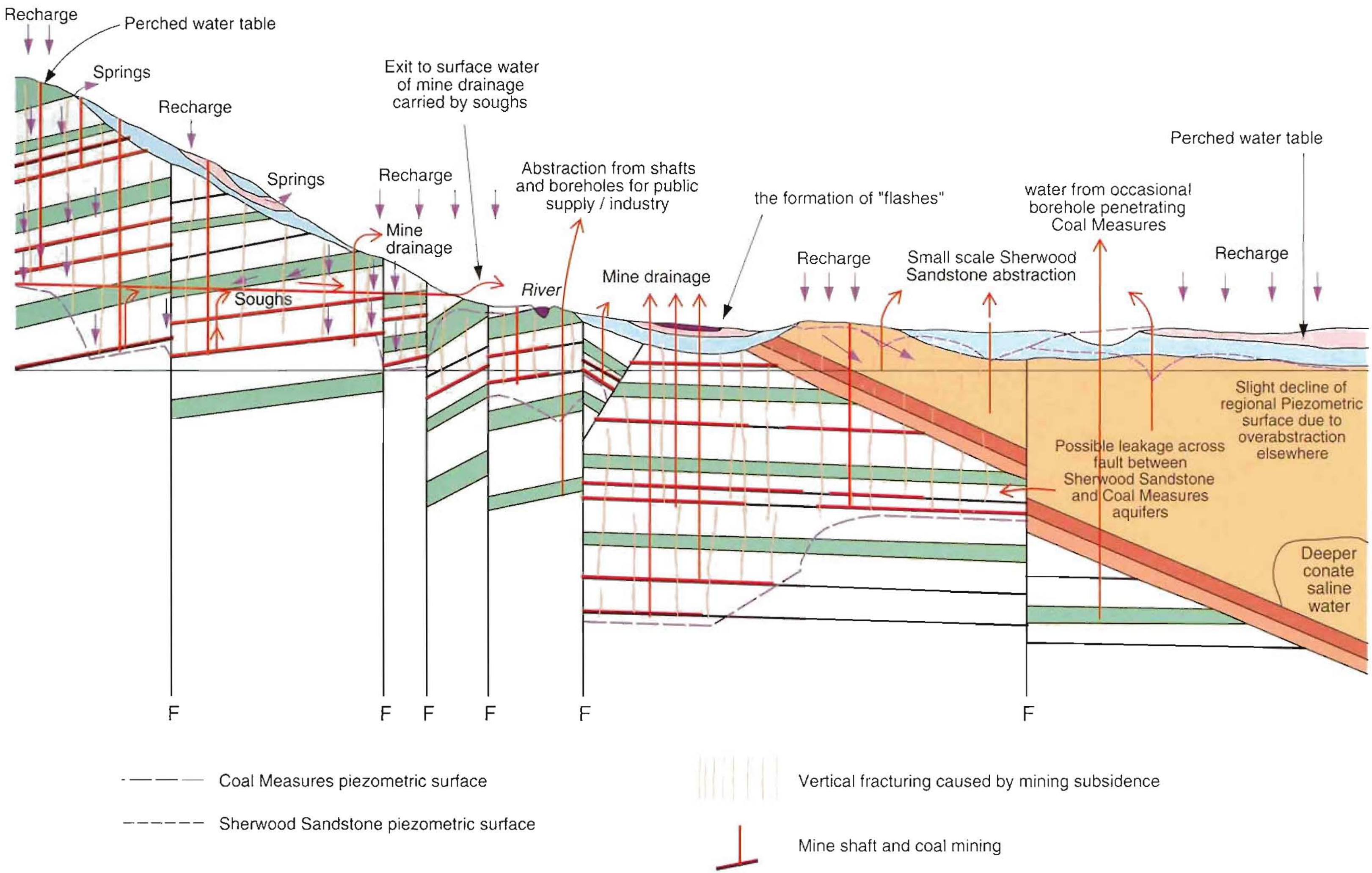


Figure 15 Groundwater abstraction and water levels at the maximum development of mining.

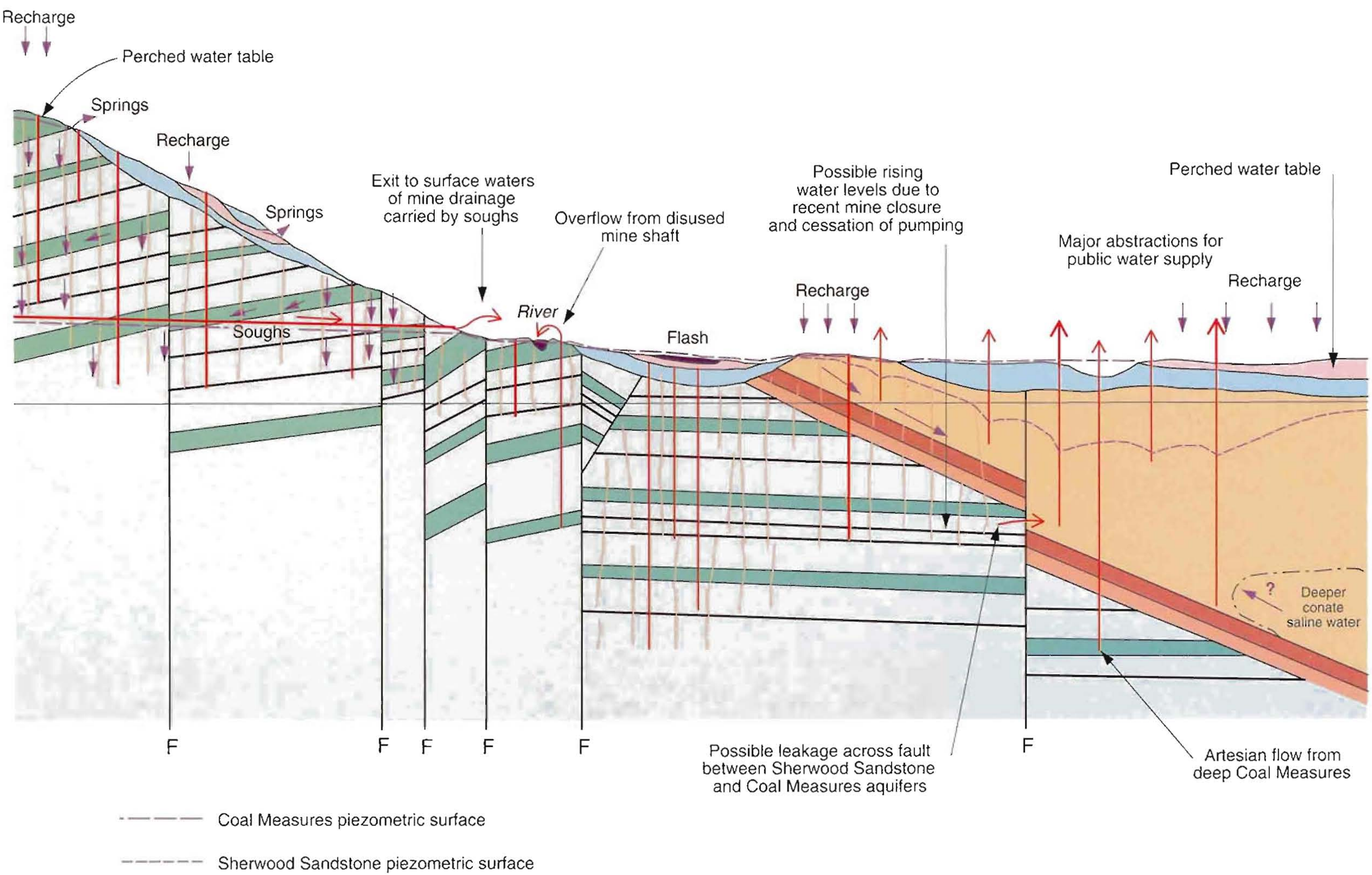


Figure 16 Groundwater abstraction and water levels: the current situation.

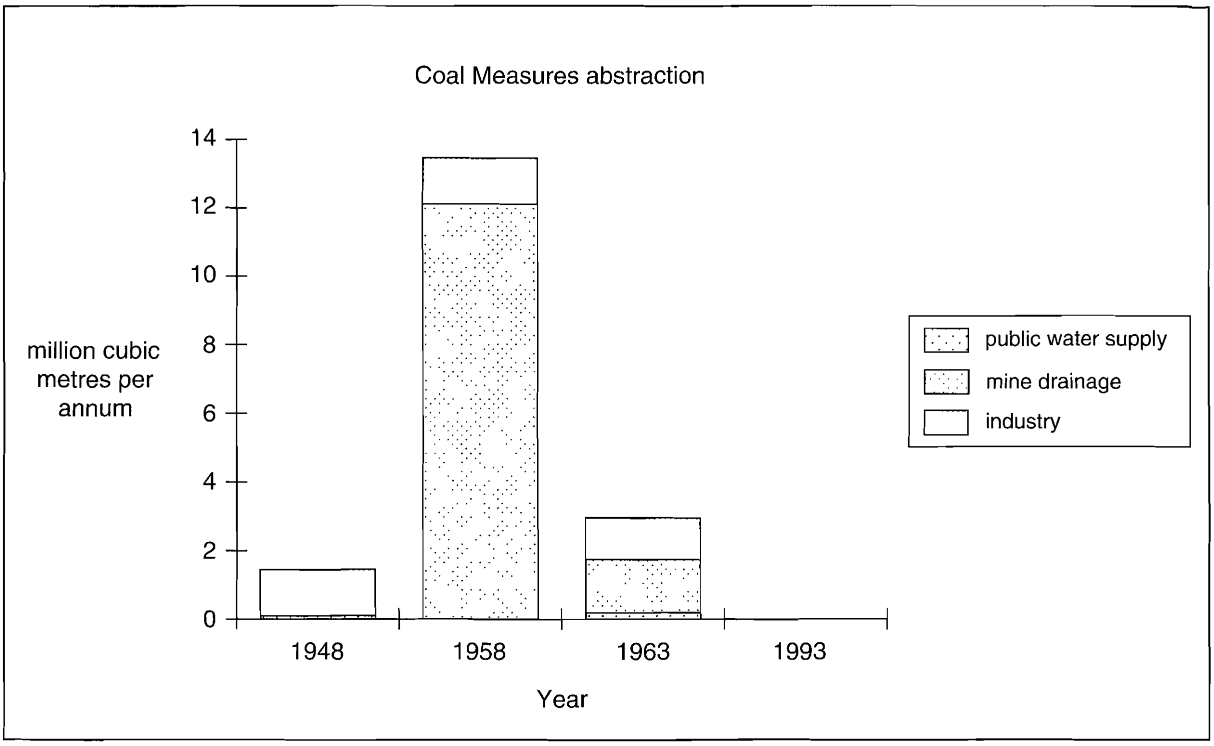


Figure 17 Groundwater abstraction from the Coal Measures.

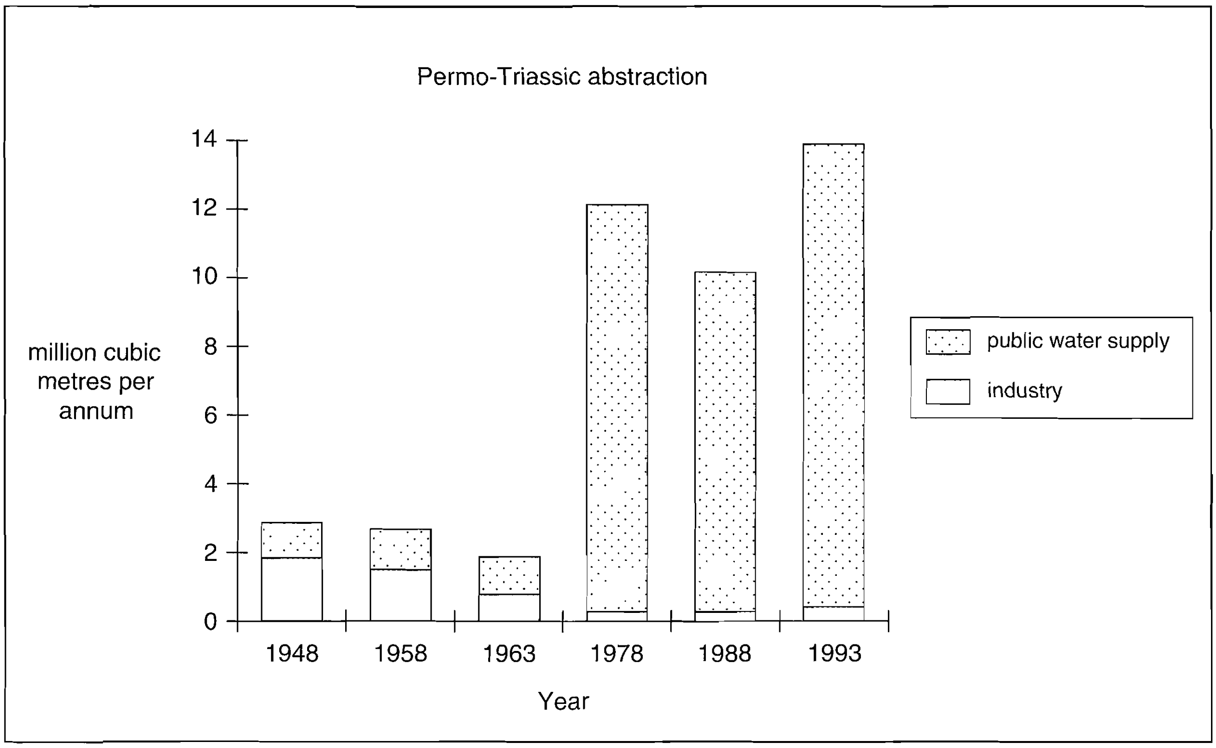


Figure 18 Groundwater abstraction from the Permo-Triassic strata.

level data available for the Wigan area before 1965, indicates that groundwater levels were gradually declining. During the 1970s, water-levels continued to decline due to the increased rate of abstraction for public supply. At the present time water movement is generally towards the depression created by the abstractions between Leigh and Golborne. Although the groundwater contours shown on the map were drawn in 1989 (Anon, 1989a) it is unlikely that the overall pattern will have changed greatly. A diagrammatic representation of the current groundwater situation in the Wigan area is provided in Figure 16.

Water levels at different locations within the Sherwood Sandstone are dependant on recent abstraction patterns. To the west of the Winwick fault, towards Ashton-in-Makerfield, water levels are rising (Figure 19) possibly as a result of rebounding water levels in the underlying Coal

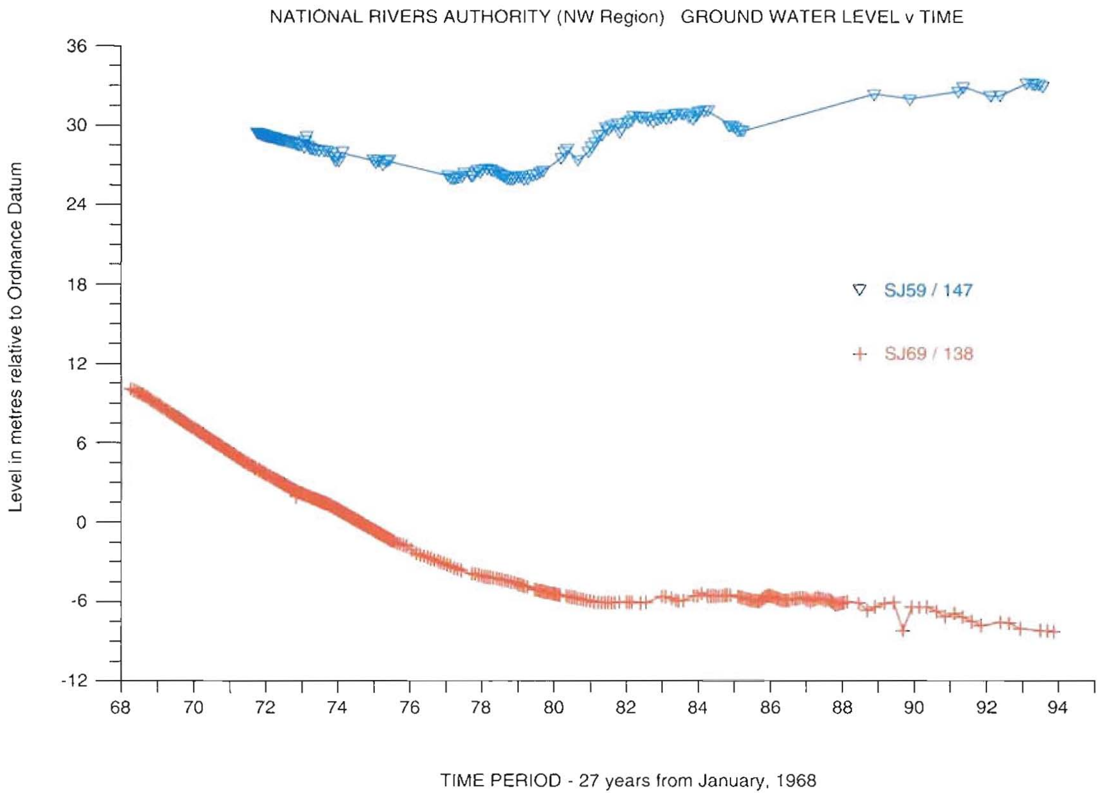


Figure 19 Rising water-levels to the west of the Winwick fault, towards Ashton-in-Makerfield.

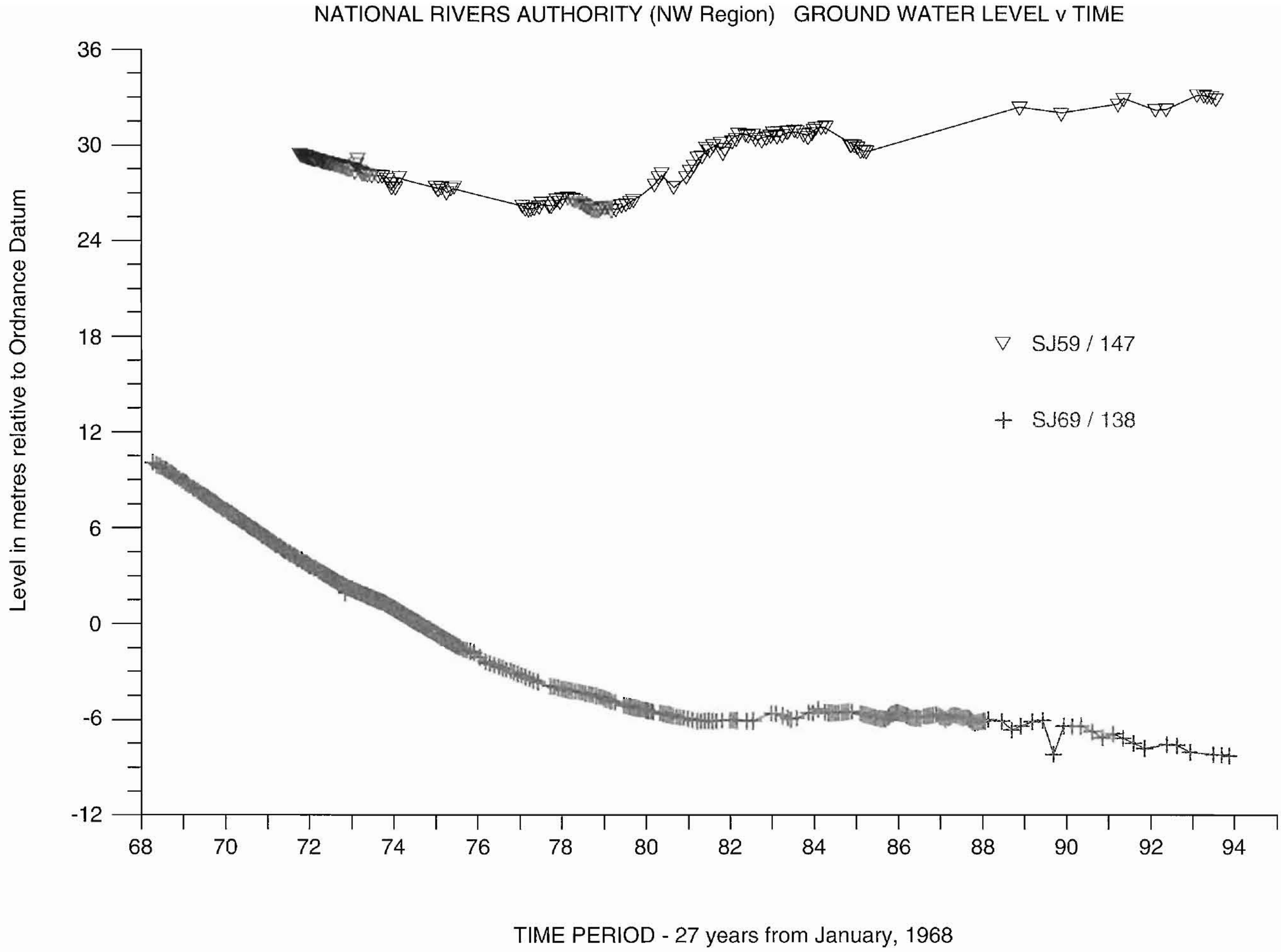


Figure 19 Rising water-levels to the west of the Winwick fault, towards Ashton-in-Makerfield.

Measures, or the reduction of industrial and localised municipal abstraction. To the east of the Winwick Fault water levels have achieved a quasi-equilibrium with a possible slight downward trend. Since water-levels are almost entirely dictated by current abstraction, any alteration of abstraction routines will manifest itself in changing water levels. This can be observed to the south of the Wigan area where the cessation of pumping from Horton Green Pumping station has led to a sharp upturn in the local water table.

Groundwater chemistry

SHERWOOD SANDSTONE

Groundwater within the Sherwood Sandstone is generally of good drinking quality. A detailed hydrochemical study was undertaken in 1981 by the University of Birmingham as part of a larger study investigating the saline groundwater within the Lower Mersey Basin (Anon, 1981a; Tellam, 1994). The age of the fresh water within the aquifer was determined by isotope studies to be less than 2000 years. Analysis of detailed sampling within the area, enabled different zones of water chemistry to be identified (Figure 20).

Type A is characterised by high sulphate, chloride and nitrate levels with relatively low calcium, magnesium and bicarbonate levels. The pH is generally low and the dissolved oxygen content high. Water with this type of chemistry is found in areas where the Sherwood Sandstone is exposed or superficial deposits are sandy, and it is indicative of recent recharge.

Type B groundwater differs markedly from type A. Calcium and bicarbonate levels are high, but nitrate, sulphate and chloride levels are low. It has high pH and low dissolved oxygen content. Type B water is generally found where the Sherwood Sandstone is overlain by glacial deposits. It is thought that it is old, pre-polluted water that has become saturated with regard to calcite and undergone sulphate and nitrate reduction.

Type C groundwater is similar to type B but has higher sodium and lower magnesium and calcium concentrations as a result of ionic exchange. It is found beneath the Wigan area at Chat Moss, where the groundwater becomes increasingly confined by the overlying superficial deposits.

Deep sources of saline water have been detected within the Sherwood Sandstone (Anon, 1981a). The high salinity (100 000 mgl^{-1} Cl) is thought to have developed during the Devensian period by the dissolution of halite. This deep body of older water is located to the south of the study area beneath Chat Moss, where high salinity has been detected above −100 m AOD. There has been some discussion concerning the movement of the saline water and the possibility of contamination of water-supply boreholes. A laterally extensive marl layer has been identified at depth in the Sherwood Sandstone of the Warrington area which is though to act as a barrier to upward movement of saline water. A similar control may operate in the Wigan area, or segregation of brine at depth may be merely a function of its higher density. However, the sinking of deep boreholes could puncture such a layer and allow upward migration of the saline water. Groundwater chemistry can also be altered by the leakage of water laterally from the Coal Measures, or vertically from the Collyhurst Sandstone. The mixing of groundwaters can lead to higher sulphate and iron concentrations and generally lowers the quality of the native groundwater.

CARBONIFEROUS COAL MEASURES

Groundwater within the Coal Measures is generally of much poorer quality than that found within the Sherwood Sandstone. Sulphate concentrations tend to be very high, usually greater than 100 mg/l and sometimes more than 1000 mg/l. The water is moderately hard with roughly 150 mg/l bicarbonate. Iron concentrations can be particularly high due to the oxidisation of iron pyrites; when the groundwater is aerated by pumping to the surface the iron can precipitate out, depositing an ochreous precipitate on pumps and screens. Groundwaters within the Coal Measures are also characterised by a low pH and consequently higher concentrations of trace metals.

Consequences of coal mine closure

The closure of coal mines in the Wigan area has left an extensive legacy of abandoned workings in an unknown condition which are steadily degrading and could, potentially, form an environmental hazard due to the effects of mineralised groundwater which they may generate. The rise in groundwater through them may also cause the movement of methane gas to the surface; this potential hazard is discussed in Chapter 13.

Coal-bearing strata contain the mineral iron pyrite (FeS_2). Mining exposes this metal sulphide to atmospheric conditions allowing it to oxidise, by a series of complex chemical changes, to the ferric ion, Fe^{3+} and producing high concentrations of sulphate, SO_4. When mines below the water table are abandoned, the pumps that have been used to dewater the mine are switched off allowing groundwater to recover towards its original, pre-mining level and, consequently, to flood the mine workings. Hydrolysis of the ferric ion exposed in the workings follows, producing ferric hydroxides, $Fe(OH_3)$, and a large amount of acidic water (Robb, 1994). Further breakdown of pyrite (FeS_2) can occur, facilitated by the Fe^{3+} in solution acting as the oxidising agent (Williams et al.,

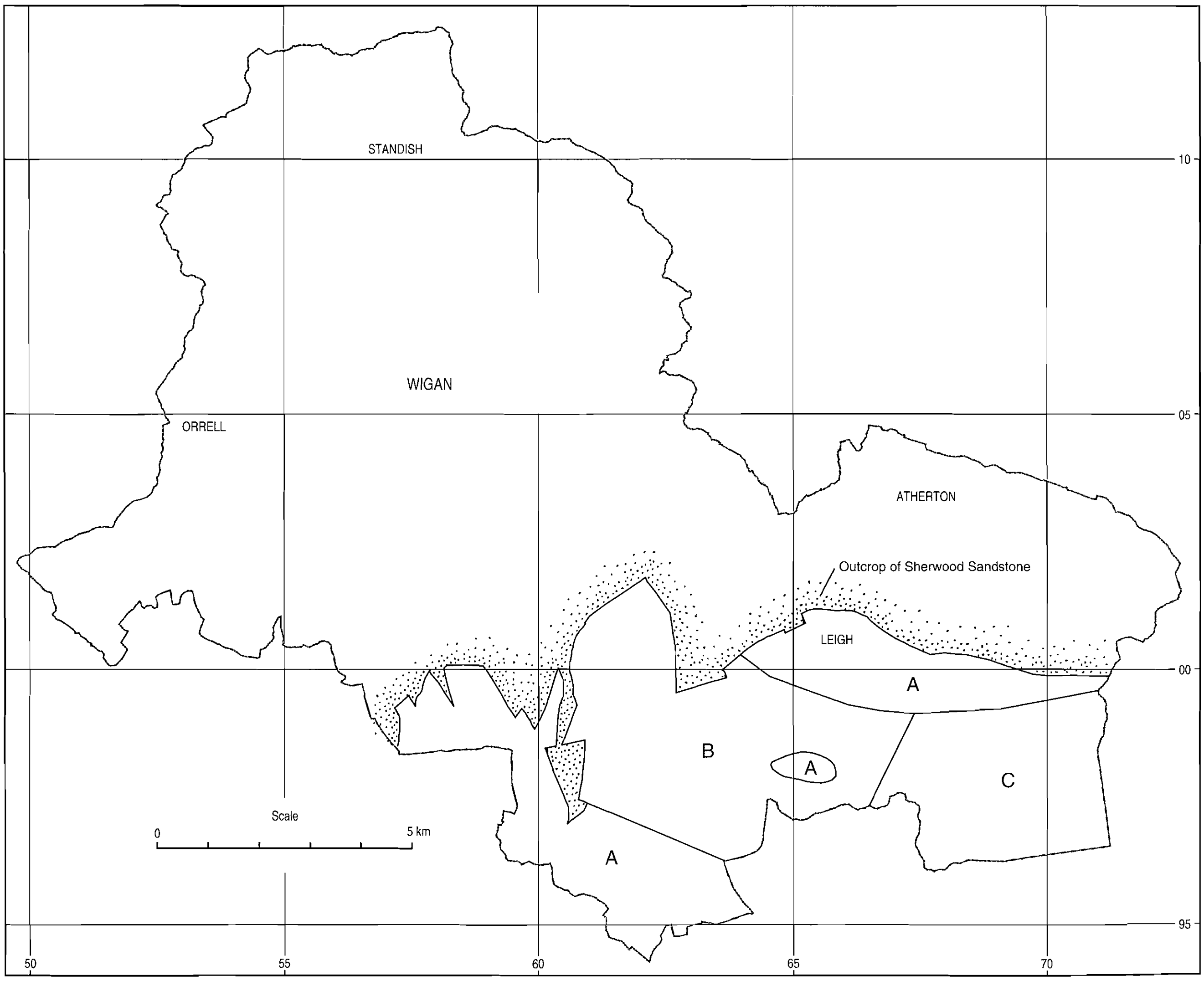


Figure 20 Zones of different groundwater chemistry in the Permo-Triassic aquifer south of Wigan.

1979). The acid produced in the above reactions may leach other metals from the formation (for example, copper and aluminium). Therefore, as a consequence of the oxidisation of pyrite and the subsequent resurgence of groundwater into a mine, very acidic mine waters can be produced with high concentrations of sulphate, ferric hydroxides, iron and other dissolved metals.

The consequence of the addition of these mine waters to water within an aquifer is to contaminate the groundwater rendering it useless for potable supply and creating a potential environmental hazard. However, if the mine waters reach the surface, further environmental damage can occur. The higher pH of water courses, combined with aerobic conditions, can cause iron to precipitate from solution in the form of hydrous iron oxides (producing characteristic orange plumes). Increased turbidity can reduce light penetration into streams, reducing the quantity and diversity of phytoplankton thus endangering other aquatic life. In severe cases, iron precipitation can be sufficient to coat the stream bed, subsequently killing all life forms.

10 Mineral resources

OPENCAST COAL

Opencast coal resources are confined to Coal Measures strata which underlie a significant part of the Wigan district either at the surface or beneath variable, and sometimes considerable, thicknesses of superficial deposits. The district has been, and continues to be, an important source of opencast coal. Although large areas of shallow coal have been sterilised by urban development, potential opencast coal sites still remain. There are currently three operating licensed sites in the district, Old Leyland Green [SD 547 010], Cranberry Ley [SD 562 022] and Bag Lane [SD 664 044]. Details of sites worked in the Wigan Metropolitan Borough are given in Appendix II.

The area of shallow coal shown on Map 5 has been defined by the crop of the Arley Mine, the lowest coal of potential interest, and the base of the sandstone above the Riding Coal, which is the uppermost seam of economic interest. However, the bulk of opencast coal mining activity in the district has been at, or above, the King/Queen coals, although the Plodder Coal has been worked locally.

Modern opencast coal mining started as an emergency measure during the Second World War and the earliest workings in the Wigan district date from this period. Opencast coal mining has continued in the area up to the present, although there was a break in activity from the late 1950s until the early 1970s. However, most of the sites have been small and well below the national average in size, with reserves of less than 0.5 million tonnes.

Opencast coal is a relatively low cost source of energy. It can be extracted cleanly and may be of high quality with low ash and chlorine contents. By blending with deep-mined coal with higher ash contents it can be used to increase overall grades. Although the boundaries of opencast sites are limited by roads, railways, urban areas and overburden ratios, within the worked area, a high proportion of the coal in place is recovered, often from very thin seams (if of adequate quality). Thus most of the coal produced by opencast mining could not be recovered by deep mining.

Originally, overburden to coal ratios were small and early sites were shallow. However, the economics of opencast mining have changed with time allowing coals with higher overburden ratios to be extracted. Consequently some areas have been worked on more than one occasion to extract deeper seams. However, in general, more recent working (post-1974), will have exhausted the workable opencast coal resource. Nevertheless, former areas of opencast coal extraction may still be included in future planning applications for adjacent areas to allow for ancillary activities such as overburden stocking.

GLASS SAND

Large parts of the Lancashire Plain are covered by extensive deposits of wind blown sand known as the Shirdley Hill Sand. The sand, which is typically only about 1 m thick, is younger than the glacial deposits and lies immediately beneath a cover of topsoil. The Shirdley Hill Sand is believed to have been used in glassmaking since the late 17th century. However, it was the development of St Helens as a major glassmaking centre, particularly after the Pilkington family took an interest in the industry in 1826, that increased the importance of this local resource. The sand has been worked extensively in the Ormskirk/Rainford area for the production of container (bottle) glass and flat (window) glass. It was the latter market which was the most important and for many years, up until the mid-1970s, the Shirdley Hill Sand was mainly used in the manufacture of flat glass at St Helens. However, the thinness of the deposit and consequent high working costs led to their gradual replacement by Chelford Sand from Cheshire and the flat glass industry in St Helens is now wholly reliant on this source.

The Shirdley Hill Sand is characteristically uniform in both composition and grain size distribution, reflecting its wind blown origin. Most of the sand particles fall in the range 500 µm to 125 µm, which is ideal for glassmaking but unsuitable for construction use. For flat glass manufacture, typically the top 0.5 m to 1 m of purer sand beneath the topsoil was removed. Here the action of peaty groundwater had leached some of the iron with the effect of upgrading the upper part of the deposit. The sand was washed prior to use and typically contained 97% SiO_2 and 0.1–0.12% Fe_2O_3, the latter component being the most critical for glassmaking. The presence of alumina was advantageous as this is a normal component of the glass batch. Because of the thin nature of the deposit large areas were rapidly worked and restored by installing drainage and spreading the topsoil behind the advancing face.

Although most of the sand workings were in the area to the north and north-west of St Helens, some extraction took place in the south-western part of the Wigan district in the period 1931–1950 (Taylor, 1967). However, because the deposits are so thin and such large areas of land would be required to maintain production, it is unlikely that the Shirdley Hill Sand will be used as a source of glass sand in the future.

CLAY

The clay resources of the district comprise superficial deposits of till (boulder clay) and Carboniferous (Namurian and Westphalian) mudstones and fireclays. Both types have been used in brickmaking in the past but there are no currently active brick clay workings. The only clay extraction within the district is at Crankwood [SJ 624 998], near Abram, where very small amounts of till are worked in a site adjacent to the Leeds and Liverpool Canal for use as a 'puddling clay' by the British Waterways Board.

Local brickworks, mainly producing 'common' bricks from locally won raw materials, were formerly a common feature in many industrial areas of Britain. However, in the last two or three decades there has been a major rationalisation of the brick industry which is now based on a small number of plants operated by a limited number of companies. With the demise of the 'common' brick, the main product is now high-quality facing bricks which are marketed on the basis of their aesthetic qualities.

There are no brickworks in the Wigan district, the last at Bispham Hall [SD 522 031], which used locally-won Lower Coal Measures mudstones and fireclays, closed in the mid-1970s. The Ravenhead brickworks at Upholland lies just outside the district to the north. Here carbonaceous shales within the Lower Coal Measures are worked but most of the raw material requirements are imported from quarries elsewhere.

The suitability of a clay for making bricks depends on a number of factors. Whilst a wide range of clays have been used in brick manufacture in Britain in the past, modern brickmaking technology is highly dependent on raw materials with predictable and consistent firing properties. The generally heterogeneous character of till, therefore, limits its use. The term 'fireclay' is used in a commercial sense and is restricted to the fine-grained seatearths or seatclays, which commonly underlie coal seams. Fireclays were originally valued as refractory raw materials and in pipemaking but changing technology has resulted in the demise of the clay's traditional markets. However, some fireclays may exhibit relatively low iron contents compared with other brick clays and are now valued for the manufacture of buff-coloured facing bricks. Thus, the clay resources of the district are confined to Carboniferous mudstones and possibly fireclays. These occur beneath a thick overburden of superficial deposits over large areas which would preclude working.

Both fireclays and mudstones occur in association with opencast coal with which they may be worked. However, this is only rarely the case, not only because of their generally highly variable quality, particularly of fireclays, but also for operational and planning reasons. For example, opencast coal sites are usually worked rapidly and the capacity to produce clay often exceeds the demand for the mineral. Whilst Carboniferous mudstones and fireclays are a potential source of brick clay, their suitability for brick manufacture depends, in part, on their carbon and sulphur contents. Both may lead to firing problems (the phenomenon known as 'black coring'), and sulphur may also give unacceptable emission levels. In general, carbon and sulphur levels should be less than 1.5% and 0.2% respectively, although the ease with which carbon burns out and blending may permit some tolerance in these figures. Blending of different clays has become an increasingly important feature of brick manufacture in recent years and it is now common for brickmaking plants to obtain their raw material requirements from several different sources. Elsewhere sandstone and brick clays are sometimes worked in conjunction.

SAND (AGGREGATE)

The sand resources of the district may be divided into two broad categories:

1. Superficial or 'drift' deposits, consisting mainly of glacial sands.

2. Bedrock or 'solid' deposits, consisting of sands and sandstones of the Triassic, Sherwood Sandstone Group.

Superficial deposits

Deposits of sand associated with till (boulder clay) and late glacial drainage are fairly widespread in the Wigan district and have been of particular importance as an aggregate resource in the area to the north, near Standish, where most of the recent operations have been located. The only extraction is currently at Worthington [SD 572 118].

For the most part, the deposits are fine-grained and comprise sands, rather than gravel, which have been derived from local Carboniferous sandstones. They are usually suitable for use in mortar and asphalt and, after washing, for use as the fine aggregate in concrete but are at the fine end of the specified range.

Deposits of glacial sand tend to form extensive areas of fairly level or undulating, well-drained land that have often formed attractive sites for towns and villages. However, the deposits may otherwise be covered by significant thicknesses of till and in some cases take the form of lenticular bodies of sand deeply buried within substantial thicknesses of till. Such concealed deposits are not easily found and their extent, thickness and overburden ratios are not known. However, it is possible that they may provide worthwhile sites for future working.

On the basis of the limited information available, the areas of Late Glacial Flood Gravels shown on the geological map to the south of Leigh are fine-grained and are not thought to be a significant resource of sand and gravel.

The Shirdley Hill Sand present in the south-western part of the Wigan district is not of commercial value as a construction sand because of their limited thickness and unusual particle-size distribution.

Bedrock deposits

To the south of Wigan, Triassic sandstones of the Sherwood Sandstone Group comprise the flat lands of the south Lancashire Plain. These rocks usually occur as red sandstones of low crushing (compressive) strength that are overlain by thick deposits of till, although occasionally the overburden is sufficiently thin to provide extraction sites.

These sandstones are currently worked at Bold Heath and Croft, both outside the Wigan district. They are worked as conventional quarries and the sandstone sold as crushed material for construction fill. The crushed rock is quite friable and easily disintegrates. It is too weak for use as concrete aggregate or as roadstone and does not conform to any of the British Standard specifications.

The upper part of the sandstone, immediately below the drift cover, is sometimes weathered to the extent that the cementing material between the sand grains has disintegrated leaving the original quartz grains in the form of a sand. Such deposits are sometimes worked for sand and, as a group, known as 'solid' deposits. Solid deposits include all pre-Quaternary stratified sands, together with the weathered parts of sandstones that can be worked without substantial crushing. However, the distinction between a weakly cemented sandstone and a dense sand is not always easily drawn and there is sometimes some confusion in terminology over solid sand deposits.

The weathered portions of the Sherwood Sandstone, or fine material produced by crushing the rock, generally do not have an ideal particle size distribution for the production of sands for use in mortar, concrete or asphalt. Usually the sand is too fine grained for concrete aggregate and requires a significant amount of washing and slime removal to produce a mortar or asphalt sand, treatment which has proved uneconomic in the past in the face of competition from more easily worked sources of glacial sands. However, a proposed new working is under development south-east of Leigh [SD 695 987] which is expected to produce a sand for mortar and asphalt by processing the weathered upper part of the sandstone. The sandstone also contains a small proportion of pebbles.

SANDSTONE

Carboniferous sandstones from the Millstone Grit and Lower Coal Measures have traditionally been a source of building stone and flagstone in Lancashire. The Cannel rock and the sandstone above the Ince 7 foot were worked for local use on the Haigh Estate. Near to Haigh village both the Trencherbone rock and the Toddington Delf were also worked (Anderson and France, 1994). During the last 50 years these markets have declined and sandstone is now mainly used for the production of crushed rock. Although sandstones within the Coal Measures occur extensively in the Wigan district, significant areas are covered with superficial deposits and resources are small. There are no active sandstone workings, although the Nob End Sandstone has been worked for crushed rock to the north-east of Leigh. Just outside the western boundary of the district the Crutchman Sandstone, north of Billinge, and the Old Lawrence Rock at Appley Bridge have also been worked in the past.

In general, the Carboniferous sandstones in Lancashire are too weak and susceptible to frost damage for them to be used for roadstone or concrete aggregate. They may be used in road construction below the level of possible frost damage and for some of the less demanding concrete applications but, for the most part, crushed Carboniferous sandstone is used as a construction fill. Sandstones within the Triassic, Sherwood Sandstone Group are usually substantially weaker than Carboniferous sandstones. They are not worked in the Wigan district but where unweathered might find application as a construction fill.

PEAT

An extensive area of lowland peat occurs on Chat Moss in the extreme south-eastern part of the area, which extends into adjacent parts of the Salford district. The peat deposits cover an area of 2587 ha and consist of raised bogs which are characteristic of an almost, or completely, flat underlying topography. The deposits have been extensively worked for horticultural purposes, either for use as a growing medium or soil conditioner. Planning permission for peat extraction covers 305 ha, both in the Wigan and Salford districts (Anon, 1994a) There are two current workings in the Borough but most are in adjacent parts of the Salford district.

11 Coal mining

INTRODUCTION

This Chapter and Map 9 indicate areas where coal mining is likely to have taken place within the Wigan Metropolitan Borough, discuss the geological consequences of such working, indicate methods used to investigate the presence of past working and list some of the remedial measures which may be used.

Information provided by British Coal, at 1:25 000 scale, derived from their digital plans database, records 36 seams as having been mined within the Wigan Metropolitan Borough. These are listed in Table 3. Original plans were not used in this study and the British Coal seam correlations have been accepted. The coal seam nomenclature adopted for this study follows the Standard Names for the Lancashire and Cheshire Coalfields compiled for the National Coal Board Western Area (Ridgway, 1983) and is described in more detail in Chapter 7.

Owing to the lateral variation in the succession of strata across the area it was only possible to record whether a particular seam had been worked within the district; the Wigan and Manchester memoirs of the Geological Survey (Jones et al., 1938) remain the most detailed published descriptions of seam variation. The disposition of the major coal seams is described in Chapter 8 and is shown on the generalized vertical section (Figure 3).

Information, available since the last British Geological Survey revision of the area, in the form of site investigation reports, borehole logs, and the completion plans of British Coal Opencast operations has shown the existing geological map to be in error in some areas. However, although the general disposition of the strata is essentially correct, errors in outcrop position of the order of 200 m have been found and in places there are significant discrepancies (for more details see section Chapter 7 and Map 2).

There is some uncertainty as to whether the Pemberton 4 ft (underlying the Pemberton 2ft) has any recorded workings in the area.

HISTORY OF MINING AND MINING METHODS

Although sometimes haphazard, the mining methods employed in the district have shown a relatively systematic

Table 3 Coal seams shown on British Coal plans known to have been mined in the Wigan Metropolitan Borough.

	Standard Name	Alternative or local names	Old workings in opencast sites?
1.	Worseley 4 Feet	Bin	Yes
2.	Riding	Ashclough	Yes
3.	Park Yard	Bulldog	
4.	New Mine Tops		
5.	Lyons Delf		
6.	Ince Yard	London Delf	Yes
7.	Bulldog	Fiery	
8.	Ince Deep Yard	Deep Yard	Yes
9.	Crumbouke	Ince 4 ft, Shams, Potato Delf	Yes
10.	Brassey	Ince 7 ft	Yes
11.	Rams	Ince Furnace	Yes
12.	Pemberton Yard		
13.	Pemberton 5 ft	Higher Florida	Yes
14.	Pemberton 2 ft		Yes
15.	Black and White		Yes
16.	Doe		
17.	Wigan 5 Feet	Five Quarters	Yes
18.	Wigan 4 Feet	Hell Hole	Yes
19.	Wigan 2 Feet		Yes
20.	Trencherbone	W 6 Ft, W 9 Ft, Top Roger	Yes
21.	Peacock		
22.	Sir John	Bickershaw Yard	
23.	Flaggy Delf	Little	Yes
24.	Cannel		Yes
25.	King		Yes
26.	Queen		Yes
27.	Ravine	Plodder	
28.	Yard Tops		
29.	Yard	Orrell Yard	Yes
30.	Half Yard	Bone	
31.	Three Quarters	Cockloft	
32.	Smith	Rushy Park, Orrell 5 ft	
33.	Arley Mine	Little Delf, Orrell 4 ft	
34.	Pasture		
35.	Cannel Mine		
36.	Lower Mountain		

development through time (Burke, 1988). An appreciation of the processes employed is helpful in understanding the possible conditions below ground and hence their implications for planning, site investigation and development.

The detailed mining history of much of the area is described in a number of published and unpublished books and reports including: Anderson, 1975; Anderson, 1979; Anderson and France, 1994; Hannavy, 1990. Although often dealing with social history, these contain significant information relating to the workings and shafts at individual collieries. They are a valuable source of information for planning site investigations and interpreting their results, particularly where plans or other records do not exist. Even where plans do exist they may be incomplete and/or inaccurate (Hellewell, 1988).

The extraction of coal in the Wigan area has been carried out for at least seven centuries. Almost the whole the area of the exposed coalfield, Coal Measures rocks not overlain by Permo-Triassic strata, has attracted the attention of miners at one time or another and a number of coals have also been worked at depth beneath the Permo-Triassic cover (Figure 2). Workings have been uncovered which may date from Roman times and it is certain that coal exposed at the surface was dug for local, domestic use since its worth was first identified. The ancestors of the Earl of Crawford are said to have worked cannel at Haigh from the beginning of the fourteenth century (Anderson, 1975). The earliest workings were restricted to extracting coal from near outcrop, where superficial deposits were absent or very thin and where coal could be seen in valleys or slopes. As techniques improved it became possible to dig further into seams as they dipped into the ground and, as boring methods were developed, to locate seams not exposed at the surface.

The Great Wigan Coalfield contains a number of thick seams at relatively shallow depths, although the disposition of the coals is complicated and disrupted by widespread faulting. Several seams are of extremely high quality, and Wigan cannel was particularly valued. In the mid-1800s there was a clear distinction in the Wigan area between coal and cannel, many companies listing themselves as 'Coal and Cannel' companies. Figure 21 indicates areas in which it is most likely that coal would have been near the surface and consequently mined at an early date.

An area particularly suitable for extraction by early, relatively primitive methods was that to the west of the centre of Wigan, known locally as the Orrell coalfield, where the thick and extremely high quality Arley Mine (Orrell Four Feet) and Smith (Orrell Five Feet) seams crop out. The upper of the two seams was nowhere more than

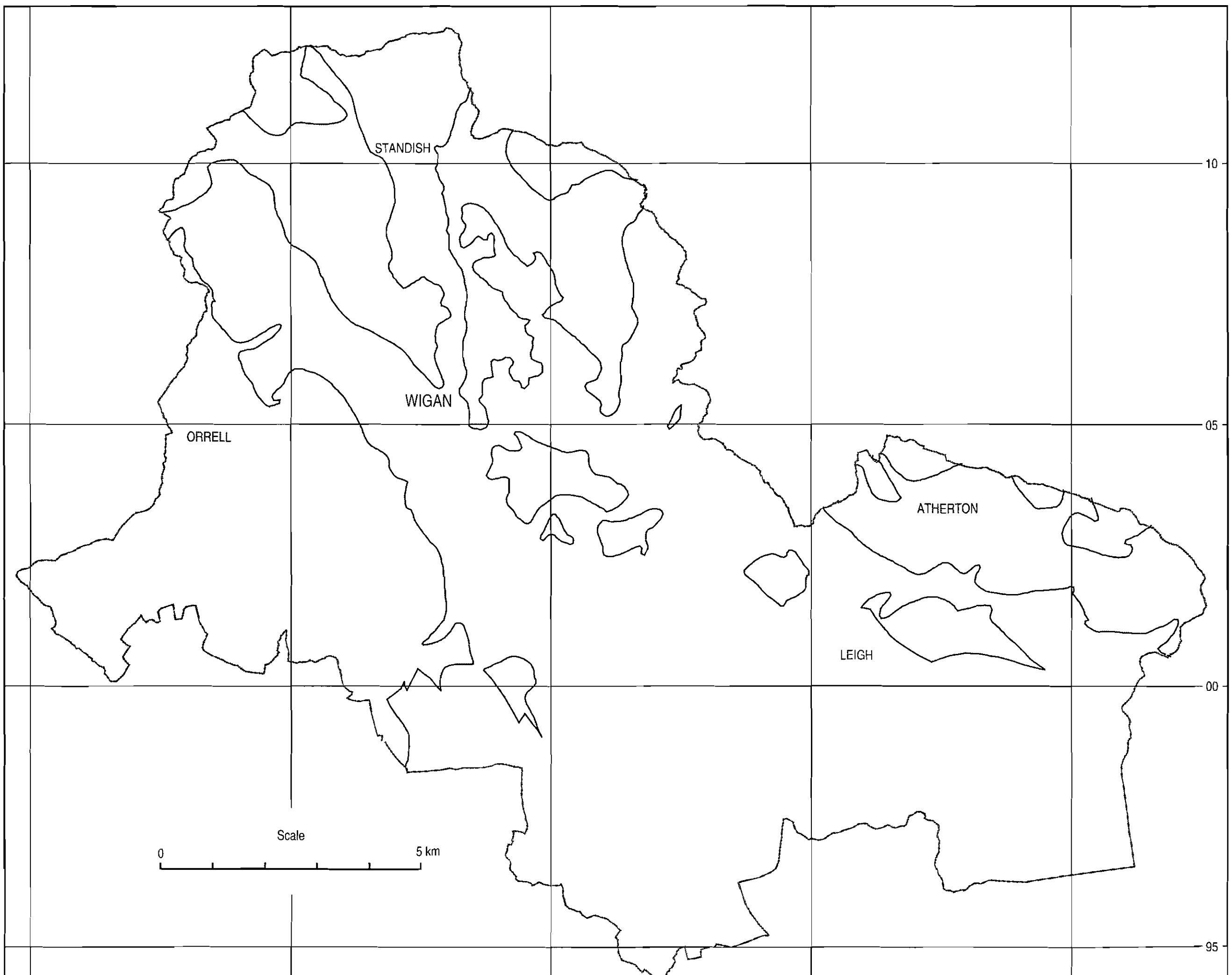


Figure 21 Shaded areas show where coal seams crop out near the surface in the Wigan area and coal is likely to have been mined at an early date.

80 m below the surface within the coalfield and, consequently, was easily exploited by 18th century methods of working. Anderson (1975) described the Orrell coalfield as having been worked, from at least the start of the 16th century, by small groups of pits (vertical shafts) and day eyes (horizontal adits). Indeed, Anderson stated that from the coming of inland waterways in 1742 the coalfield was worked so intensively that it was, for all practical purposes, exhausted before the coming of the railway in 1848. Thus, the Orrell Coalfield can be seen as an example of an area where it is extremely likely that shallow mine workings will be encountered in the course of new development, although few plans are lodged with the Coal Authority.

The Standish estates, to the north, were being mined extensively by the middle of the 17th century and nearer to Wigan there had been a colliery at the foot of Millgate since the 16th century. Traditionally, much of the coal had been mined for local domestic use, rather than for export to other areas.

The mid-18th century saw a rapid move from drift mining to mines with vertical shafts. The abundance of coal relatively near the surface made possible the opening of mines with shafts less than 30 m deep, though this was still a major operation by manual excavation. It was common practice to sink a number of shafts so that ventilation and the transport of coal from the face to the surface were both improved. Approximately 350 pit shafts were sunk within the two square miles of the Orrell Coalfield (Anderson, 1975).

In the earliest form of mine, the coal at the base of the shaft was worked in all directions, creating a beehive or bell shape at the foot, leading to them being called bell pits. The seam was worked until the entire structure was in danger of collapse. An example of bell pit working within the area was encountered in the Bin Mine during the opencast excavation for Great Boys (Figure 22). On the north eastern edge of the Borough, east of Tyldesley, extensive bell pit workings were recorded in the Rams seam. Most of the thicker seams in the Borough will have been worked in such a way, including those seams now beneath built up areas.

Generally, bell pits were backfilled, but this may have been incomplete and the state of compaction can be highly variable. Fill materials usually consist of silty clay and moderately to completely weathered mudstone fragments with traces of coal. Rotting timber is sometimes present. A more efficient development of this technique had evolved before the end of the 18th century where columns or pillars of coal were left to support the roof of the workings, allowing the extraction of much greater quantities of coal before collapse was likely.

The next major advance in the development of coal mining was underground working which proceeded along a seam, leaving pillars of coal for support, but sinking new shafts every 100 m, or so, to improve the transport of coal to the surface. Approximately a thousand shafts of various types were sunk in and around the Wigan Coalfield before the end of the 18th century. Typically, in the Orrell Coalfield, this practice continued until well into the 19th century but during the early part of the period a coal drawing shaft would rarely have a life of more than three years (Anderson, 1975).

Up to the last few years of the 18th century it was common for 40 per cent of the coal to be left in pillars, this method of 'partial extraction' helped to prevent, at least in the short term, collapse and subsidence at the surface. It is such workings which pose the greatest threat to development today. In about 1790 it became the practice to take out all the pillars, achieving an extraction of more than 90 per cent of the coal. Using a variety of techniques this 'total extraction' allowed the roof to collapse onto the seam pavement. No attempt was made to control the consequent movement of the strata and the resulting subsidence at the surface.

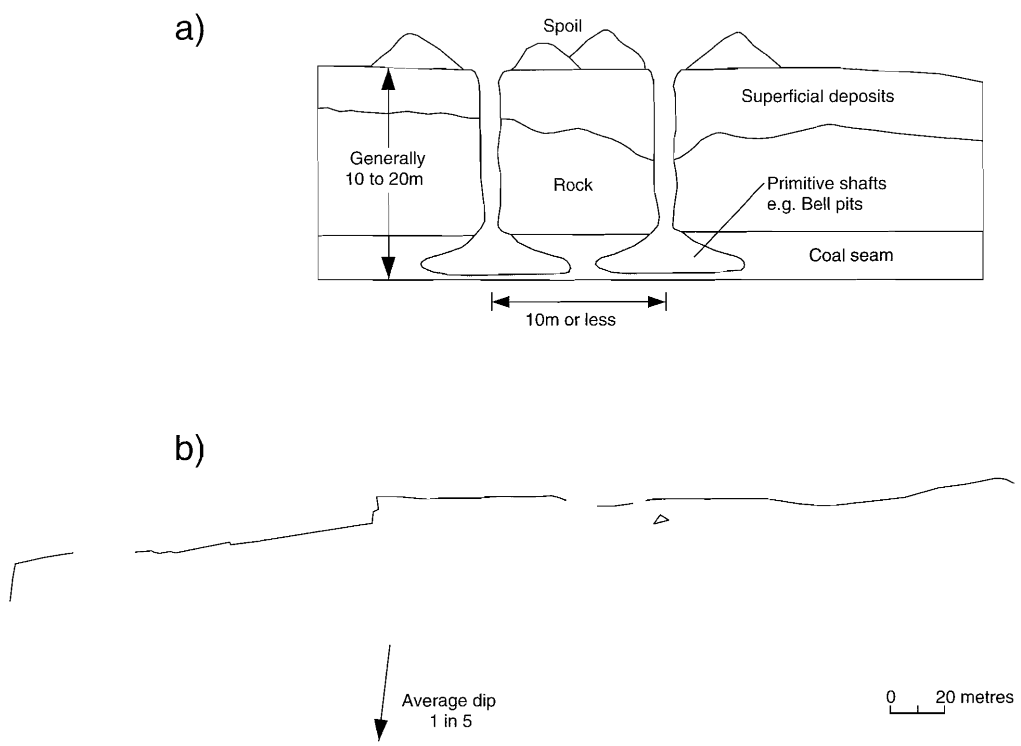


Figure 22 Diagrammatic cross section of bell pits found in opencast sites.

The Haigh Ironworks opened in Wigan in 1790 and had the local rights to build the newly developed steam pumping engines. The introduction of mechanical pumping engines to Wigan's wet and gassy mines enabled the next stage of development in the Wigan mining industry to be accomplished by allowing access to coal from deeper shafts and working further from the shaft foot. The necessity for deeper shafts required new working methods. Pit-head winding gear was developed, ventilation for the deeper seams was designed and implimented and drainage tunnels dug to keep the workings free from water. Shafts to 60 m were not uncommon by the end of the 18th century. The first pits sunk by Blundell's at Pemberton in the early years of the 19th century were 120 m deep and by the 1860s the pit was working 580 m below ground. Hand sinking, with pick and shovel, had achieved shafts 150 to 240 m deep by the 1830s and hand sinking was still common in the 1890s. Banke's Winstanley pits and Lindsay's Alexandra pits, both sunk in 1856 and considered deep pits at 240 m (800 feet), passed through seams of coal which had already been worked out and abandoned. The first shafts sunk to a depth of 305 m (1000 feet) were sunk in the 1850s by Rose Bridge Colliery and by the late 1860s the New Caroline Pit at the colliery was sunk to 762 m (2500 feet), the deepest in Britain at that time. Towards the close of the 19th century many of the coal faces in Wigan were being worked in the same way, albeit on a much larger scale, as they had been a century before.

In the early 1900s the opening of an electric power station in Wigan enabled the use of electrical cutting equipment to be widely introduced within the coalfield. The intense working of the coalfield in the 50 to 60 years before 1920, with some pits approaching depths of 1200 m (4000 feet), had resulted in an increasing number of seams becoming worked out or too difficult to exploit any further. At the time of nationalisation, in 1947, there were just over 20 working pits. These have now closed leaving coal extraction represented by a few privately owned drift mines and by opencast workings.

Many of the seams worked and abandoned in the 18th and 19th century have been exploited since the 1940s at opencast coal sites. Ancient pillar and stall workings in these seams have been revealed in many sites and give an indication of the extent of uncharted workings within the coalfield. Such areas are shown on Map 9 and listed in Table 3. Examining the nature of these exposed workings provides information about former methods of working which will assist in the design and interpretation of site investigations in areas of suspected mine workings; examples of former working methods are shown in Figure 23.

Mine drainage

Most of the mines in the Orrell belt had been drained by means of adit levels from at least the 16th century. In Lancashire and the surrounding areas these drainage adits are known as soughs. They are cross-measure drifts or tunnels, driven on a very slightly rising gradient from just above the highest flood water level of the lowest convenient stream, to intersect the seam or seams to be worked. A water level, known locally as a 'water lane', was driven from the point where the sough entered the seam, along the strike or level contour of the seam. As the depth at which seams were being mined increased so the soughs became progressively longer and more substantial engineering works. The locations of many of the old soughs, tunnels and waterways are unknown today. If they are encountered unexpectedly in the course of development, and they are still open, they can pose considerable problems. Many are believed to be at least partially blocked, and have ceased to drain the old workings causing water levels to rise in the old workings and shafts. (Further details are given in Chapter 9)

Associated mineral extraction

Minerals other than coal, such as ironstone or fireclay, were sometimes extracted from the same mines as coal. Elsewhere in the country the ironstone nodules and shales associated with coal seams were worked with the coal near outcrop. These early opencast workings are typically marked by mile long reafforested strips with lines of bell pits behind where the minerals lay deeper and had to be raised by horse gins.

Ironstone bands with an iron content between 25 and 30 per cent are present in the strata between the Ince 7ft Seam and the Bulldog Seam and some of the seatearths contain nodular ironstones. Ironstone had been worked as long ago as the early 17th century and was important during the operation of the Haigh Iron Works at Leyland Mill from 1790 to 1828. An estate map of 1796 indicates adits in the east slope of the Douglas valley from the Plantations to Brock Mill, north of which, working continued by shafts (Anderson and France, 1994).

HAZARDS ASSOCIATED WITH OLD MINEWORKINGS

Old workings in Wigan

The large-scale redevelopment of central Wigan demonstrated the problems posed by old workings to development. The thick coal seams which lie below the town centre at shallow depths are known to have been worked extensively and a number of buildings had suffered cracking, settlement or damage requiring repair or demolition. However, much of the early working was undocumented and a detailed site investigation programme was undertaken to identify the potential foundation problems due to old workings. Several series of boreholes were drilled and the results interpreted taking into account the old methods that had been employed in mining. The boreholes found evidence of workings of considerable variety and age, but also areas of unworked coal where mining had been prevented by the presence of water at the former, higher, water table. Considerable revision of initial ideas (and of the existing geological map) were required before a satisfactory three dimensional interpretation was achieved that could be used to design appropriate, cost effective, engineering solutions to the problems identified.

Uncollapsed workings in the lowest of the Wigan group of coals, the Wigan Six Feet (or Trencherbone), were uncovered less than 10 m below ground level during the construction of the new public swimming baths. The workings were believed to date from the 17th century and the survey showed them to be systematically laid out for 75 per cent extraction of the seam with a good parallel alignment of the bords (stalls), the seam dipping towards the north-east at about 1 in 12 (Figure 24). The abrupt limit to the workings in the north-east is believed to be where the coal reached the prevailing water table which, at that time, prevented further development of the mine down dip. The relative stability of the workings is attributed to the

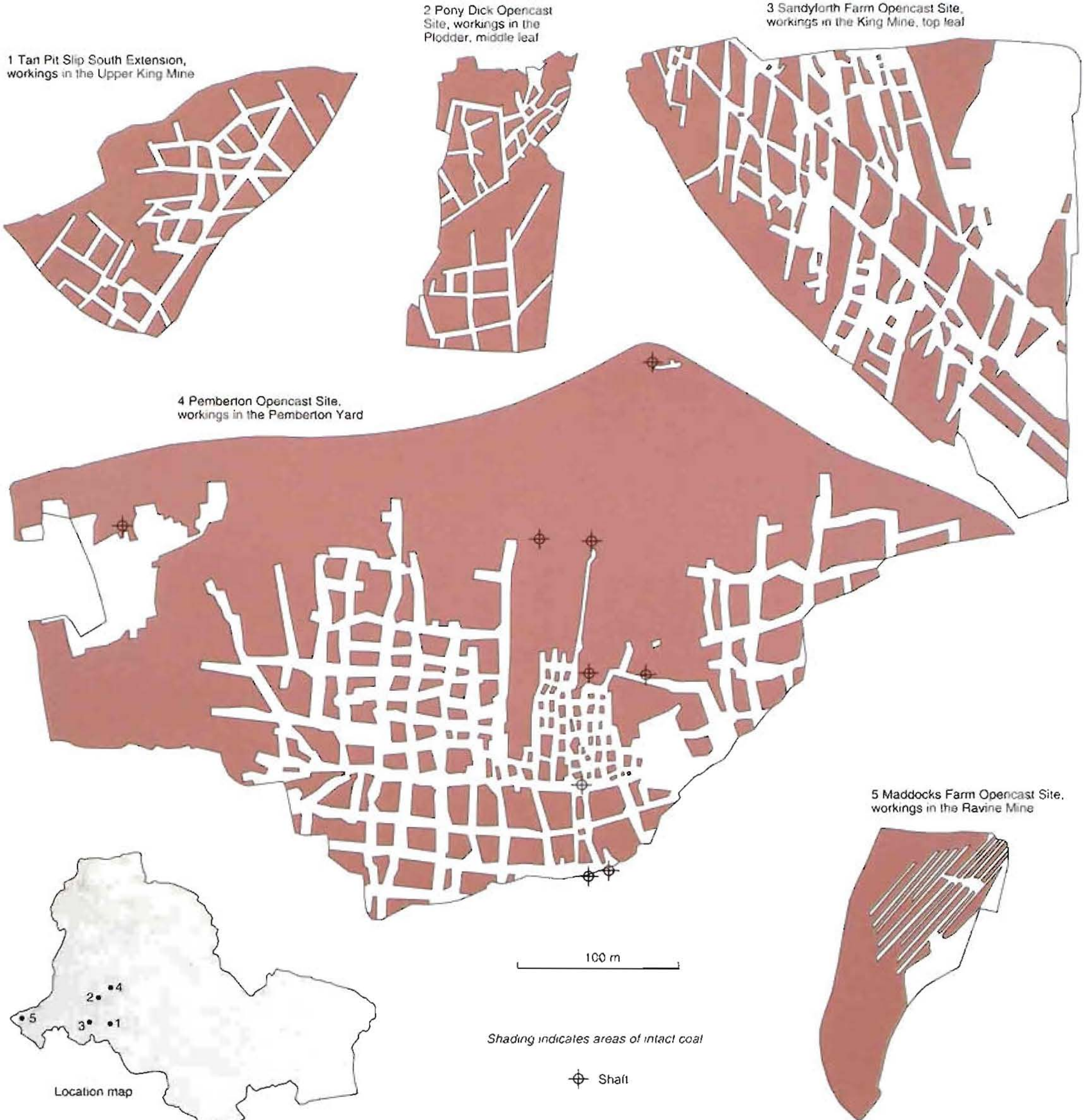


Figure 23 Examples of different patterns of 'pillar and stall' working exposed during the excavation of opencast sites in the Wigan area.

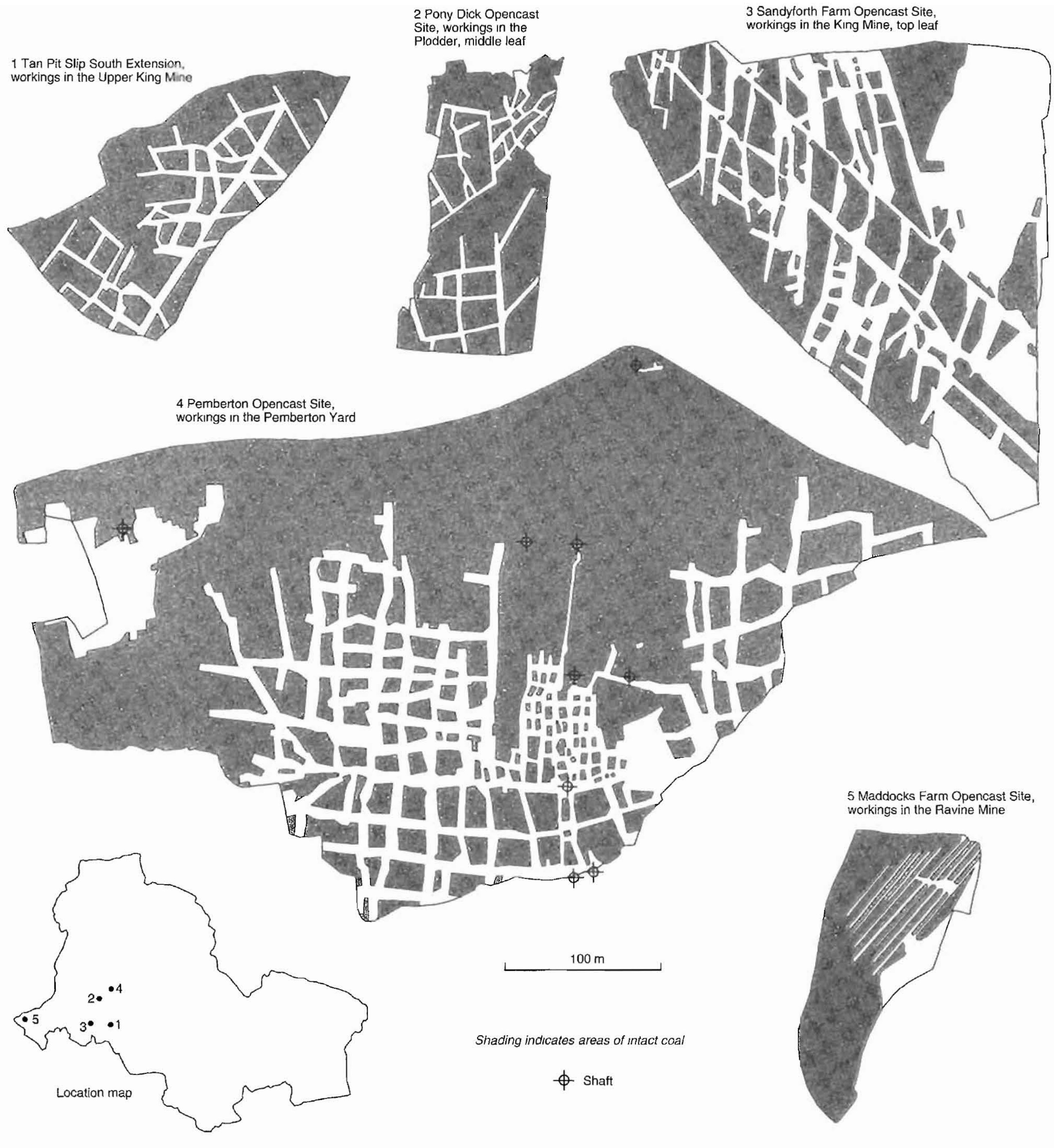


Figure 23 Examples of different patterns of 'pillar and stall' working exposed during the excavation of opencast sites in the Wigan area.

strength and soundness of the Trencherbone Rock which forms the sandstone roof. However, isolated falls had occurred up to the time of excavation. The site was excavated to the old workings and the coal removed prior to construction, with backfilling as necessary.

Assessment of mining hazard

The Department of the Environment has commissioned, and published the results of, a number of studies of the effects of mining instability on land use and development which provide guidelines for treatment where appropriate. These include: the Treatment of Disused Mine Openings (Anon, 1988a), Planning Policy Guidance 14 (Anon, 1990a), and The National Review of Mining Instability in Great Britain (Anon, 1992a). Additional guidance is given in the CIRIA special publication on construction over abandoned mine workings (Healy and Head, 1984) and in BS 5930, the Code of Practice for Site Investigations (Anon, 1981b).

The degree of hazard associated with development in an area underlain by mineworkings is extremely difficult to quantify as large variations in ground conditions may occur even within a specific site. The hazards posed by undermining to ground engineering and their investigation were described by Culshaw and Waltham (1987). An

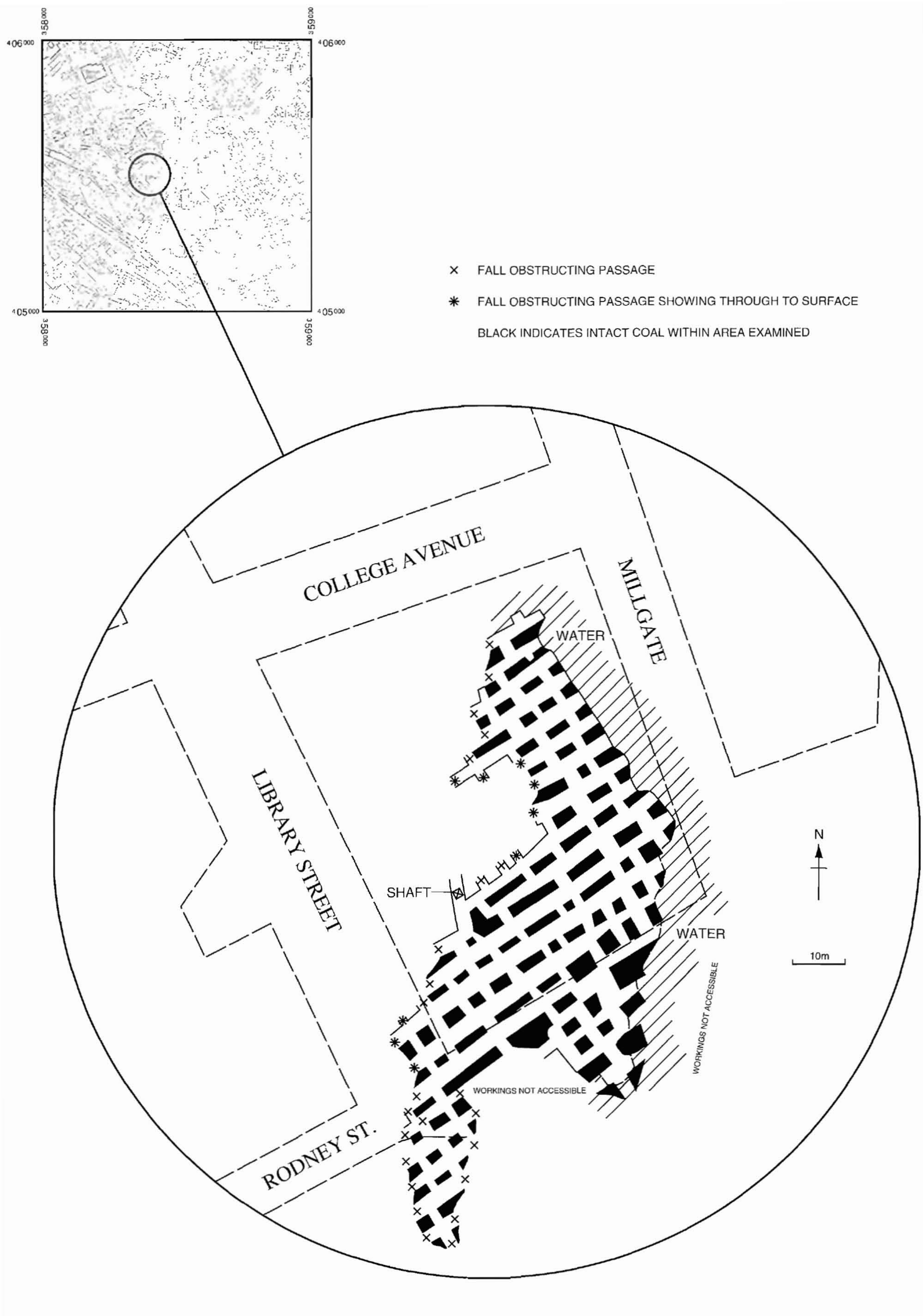


Figure 24 Workings found during the construction of the new public swimming baths showed 75% extraction and good parallel alignment of the stalls in a seam dipping towards the north-east at about 1 in 12.

approach to the strategy for making the engineering decisions on treatment when building in areas of shallow mines was described by Cole (1987).

Subsidence

When a partial extraction mine is worked it will deteriorate from the moment a void is created. In a working mine important areas, such as roadways needed for access, are kept open by maintenance and support. When a mine is abandoned the process of deterioration continues unchecked, leading to slow closure or rapid collapsed. Thus, ultimately, depending upon the geological circumstances, depth and geometry of the mine, there will come a time when crown holes or general subsidence will occur (Cole and Statham, 1992). The causes of general subsidence are such that few partial extraction mines will avoid subsidence. Only those with low extraction rates and high strength of the mineral and overlying rock, or were fully back stowed may remain stable.

In areas of partial extraction, the collapse of the workings when mining ceases may take place by several different mechanisms. The pillars may crush, strata may collapse into the rooms, the floor may heave into the rooms or the pillars may punch into the underlying strata. The resulting subsidence may be uneven, difficult to predict and the collapse may be long delayed. Construction in such areas may require engineering measures to be taken to improve the ground conditions by grouting and to protect buildings from the effects of future subsidence by suitably designed buildings, foundations and associated preventative works.

In the Wigan area there are a number of thick, strong sandstones within the Coal Measure succession (Chapter 7) which can provide sufficient support over old mine-workings, to maintain stable conditions for long periods of time. The major sandstones in the Wigan coalfield include in descending order:

- Prestwich Rock
- Nob End Rock
- Pemberton Rock
- Ravenhead Rock
- Trencherbone Rock
- Cannel Rock
- Old Lawrence Rock
- Crutchman Sandstone
- Bullion Mine Rock

When workings have been proved below a site but no plans have been found, or where workings are suspected, the mine layout and its likely condition can be predicted from a knowledge of mining methods used at the estimated date of the workings. The following features may be inferred:

1. the amount of coal extracted from each seam;
2. the dimensions of pillars left in-situ;
3. the pattern of mine roadways, their number and size;
4. the nature of connections with nearby workings;
5. the layout and condition of 'soughs' (drainage adits);
6. the nature and extent of roof support packing;
7. the probable pattern of strata movement at the time of working;
8. the simultaneous working of non coal material.

The dimensions of the pillars and stalls in old partial extraction mines were the result of the experience of the miners during the mining process, rather than by theoretical calculation and design. Important factors were the strength and discontinuities in the roof rock, the thickness of seam and the depth of the mine. The aim was to optimise the extraction of coal while keeping the mine stable. The layout of the pillars and the direction of driving the roadways were largely dictated by the dip (inclination) of the seam and the direction of the main cleat (or cleavage) of the coal which determined the plane in which it was easiest to split.

In Lancashire there was a local variant of the 'pillar and stall' method of working referred to as 'straitwork' with the roads as 'strait places'. Old workings In the Orrell Five Feet seam, reopened with a view to working the pillars, showed roads consistently 1.5 yards wide and with pillar dimensions typically 2–3 yards, but locally up to 8 yards square. Anderson (1975) gave a detailed description of the method of driving the 'straits'. In the period before 'robbing' of pillars took place, in order to achieve 'total' extraction, it was common for the waste to be back stowed in regions which had already been dug. Examples of different patterns of 'Pillar and Stall' working exposed during the excavation of opencast sites in the area are given in Figure 23.

Access roadways were often of greater height than the seam mined, but in later years, were commonly well supported by iron, stonework or brickwork because they had to remain stable for long periods during the life of the mine. Generally, the collapse of such roadways does not occur in the same manner or at the same time as the workings and may occur many years after abandonment.

In modern mining coal is normally removed completely (total extraction). The overlying strata collapse rapidly into the void left as the working face moves forward and cause general subsidence at the surface. This form of subsidence is usually completed within two to five years after the working face has moved on and its effects are more predictable than subsidence due to partial extraction. Throughout much of the Wigan area the subsidence associated with total extraction has finished, leaving a resultant lowering of the ground surface. Numerous methods have evolved for the prediction of the subsidence which occurs at the time of mining (e.g. Anon, 1975), but none can be applied with complete certainty, particularly where multi-seam working has taken place and the strata are heavily faulted.

Where deep mining has taken place beneath a site it may be assumed that subsidence will have taken place and that the subsidence might be up to the maximum total thickness of the coal extracted. This assumption extends to the area of the concealed coalfield where coal has been mined beneath Permo-Triassic rocks. A study for the British Waterways Board (Ferrari, 1988) showed that the subsidence beneath the Leigh branch of the Leeds and Liverpool Canal, where some 100 m of Permo-Triassic rocks overlie Coal Measures, greatly exceeded predictions and continued for several years after mining ceased. In order to maintain water level the canal has been raised to accommodate the subsidence and is now on embankments approximately 9 m high. An estimate of the total thickness of coal extracted from 11 seams beneath the canal is in the order of 10 m. A recent study in the Northumberland coalfield has shown a similar correlation between subsidence and the total thickness of seams worked (Whitworth, 1994).

Modern deep mining by total extraction causes few problems because subsidence is completed shortly after working stops. Ancient mining by partial extraction was usually at relatively shallow depth and subsidence effects may continue many years after working ceases. Plans or records may not exist or be inaccurate. It is these open or partially collapsed workings which may need ground improvement before development. Consequently this study has placed particular emphasis on shallow mine workings, defined here as those within 30 m of the present day ground surface.

Although most recent mining can be assumed to have been of 'long wall' type working involving total extraction of the coal, there are examples of local pillar and stall working. The Ravine seam had been worked by total extraction methods in the 1880s, but the identification of unworked coal near the surface enabled it to be mined by pillar and stall methods from adits in Bluebell Wood until as recently as 1972.

In the Wigan area the boundaries of mined areas are, in many cases, defined by faults with the number of coals worked within a particular fault block dependant on the vertical succession within it. An examination of the geological cross-section (Figure 3) shows the maximum number of seams present in the central fault trough. Reactivation of faults by undermining generally causes fracturing and disruption of strata within the fault "zone". This may lead to an increase in the porosity and permeability of the fault zone, possibly providing enhanced pathways for the migration of fluids and gases (see Chapter 13).

Abandoned shafts

A great number of shafts have been sunk in the Wigan area. While many of the earliest shafts were sunk to a single seam at shallow depth later ones may have been sunk to encounter a number of coals. The most comprehensive shaft database available is held by The British Coal Authority to whom enquiries regarding them should be made. The shaft sites and mine entries on Map 9 are reproduced from a 1:25 000 scale plan provided by British Coal. There are almost certainly old shafts, not shown on the map, which remain to be discovered within the Wigan area, for which records were not made or have been lost. ***The responsibility for locating and treating shafts at, or close to, development sites rests on the site owner or developer.***

SITE INVESTIGATION IN AREAS OF SUSPECTED SHALLOW MINEWORKINGS

The aims of a site investigation on land which may be affected by former mining are to identify hazards, and to gather information which will assist in the siting of structures, the design of ground improvement works and the design of foundations. This will include the following objectives:

1. establish whether or not mining has taken place beneath the site;
2. determine the geometry of the workings;
3. determine the condition of the workings;
4. establish the sequence of overlying strata;
5. determine the engineering behaviour of the strata;
6. determine the geotechnical properties of the materials present.

At the desk study phase, a search for old mining records may produce plans of old workings or suggestions as to the spacing and dimensions of likely pillar layouts. These will help to decide the position and spacing of the site investigation boreholes which will give the best chance of encountering old workings if they are present. However, even where plans do exist they may contain inaccuracies within the workings and their relationship to the past or present day topography may be poorly defined.

The methods of mining, and the sequence in which multiple seams were worked will significantly influence the state of the abandoned mine workings and the overlying strata. The present and former groundwater levels are also significant since they controlled mining operations before artificial drainage and are an important factor in the stability of abandoned mines, influencing the rate of deterioration of pillars, roof and floor and affecting the stress imposed on pillars if the mine floods. Many mines which were drained for working are now flooded.

Methods employed for the investigation of old mine workings and shafts are well documented (Anon, 1976; Bell, 1975 and 1986) and are usually based on patterns of boreholes or probes spaced so as to intersect the voids in the old workings and to minimise the possibility of all the boreholes passing through pillars. The optimal use of boreholes is achieved if the pattern is designed on the basis of local working methods or mine plans, if available.

Boreholes on their own are unlikely to be successful in finding shafts, but the success rate is much improved if boreholes are sited using targets identified by other techniques, such as geophysical methods. Once located, a borehole may be used to prove the total depth of a shaft and the composition and compaction of the backfill. Great care must be taken to protect the drilling rig and the drillers when drilling on old shafts in order to avoid the risk of the drilling rig falling into the void if the shaft fill collapses.

The following methods may be employed to investigate shafts and old workings and the combination of several methods used in conjunction may prove more successful than a single method or methods used in isolation:

1. Aerial photographs can identifying anomalous tonal or topographic features indicative of old shafts and pits.
2. Geophysical surveys may be very successful where there is sufficient contrast in geophysical properties between the empty shaft, its lining or the material with which it has been filled and the surrounding ground (McCann et al., 1987; Bell, 1988). Methods include: resistivity, electromagnetic, micro-gravity, magnetic, seismic tomography, and ground probing radar.
3. Trenches, pitting and soil stripping may be useful methods in themselves or to investigate targets identified by other means.

Where mining is known to be present the quality of the overburden rock may give an indication of the likely state of the mine. For example, good quality rock which is moderately fractured and largely unweathered is typical of the condition of rocks above partial extraction mines showing little sign of collapse. Therefore, it is important to assess the condition of the overburden, by engineering geological logging (especially fracture logging) of core possibly in conjunction with geophysical logging of the borehole itself.

PREVENTIVE AND REMEDIAL TECHNIQUES FOR MINING SUBSIDENCE

Preventive measures can be applied before mine instability has affected the surface or to limit the effects of subsidence which has started. Where serious damage has occurred and hazard has become unacceptable then remedial measures may be taken to rectify the problem.

The most effective preventative measure is to avoid building on undermined ground but this is not always an option available in areas where other planning issues take precedence. Two courses of engineering action are available and either or both may be applied:

1. the mine may be stabilised and subsidence stopped;
2. buildings may be constructed, or strengthened, to accommodate the ground movements caused by subsidence.

Mine stabilisation

Mine stabilisation may be achieved by strengthening mine pillars and the installation of additional support but this requires access to the mine which may have no entrance, is likely to be unstable and may be flooded. This technique is rarely applicable in abandoned, deteriorating, coal mines. The induced collapse of a mine by destruction of the supporting pillars by blasting or dynamic compaction has been used but is not widely applicable in coal mining areas.

The most common way to stabilise a mine is to infill the voids with a grout composed of material such as cement, sand and pulverised fly ash which is pumped into the mine via a series of surface boreholes. In this way the mine is sufficiently filled and the roof supported to avoid the worst effects of subsidence reaching the surface. This method of treatment does not require access to the mine by personnel, is well established and has been widely applied in coal mining areas. A number of examples where grouting has been used in the Wigan area are indicated on Map 9, including the stabilisation of ground for the inner ring road.

In shallow undermined sites, excavation to mine level, removal of the coal pillars and backfilling prior to development may be possible and offers the prospect of selling the coal to defray the expense of ground treatment.

Shaft treatment

Shafts should be treated to a standard suitable for the subsequent use of the site. In an urban area this usually involves a reinforced concrete capping, keyed into bedrock and backfilled to the surface. In some cases manhole access to the shaft may be maintained for monitoring purposes. As part of the programme to restore derelict sites WMBC have identified a number of shafts over recent years; many have been capped to the standards set by British Coal. Information on the state of known shafts is also held by the Manchester Geological Unit, Manchester University on behalf of the Mines and Quarries inspectorate.

In the past, when shafts were filled, the fill may have been placed on a platform of girders or wooden beams placed at some point below the top of the shaft, commonly at rock head, which may deteriorate and collapse. It is essential to determine the condition of shafts and their filling/capping prior to development. Even where a shaft has been filled within the last 40 or 50 years, the backfill may be of a highly variable composition and degree of compaction, such that voids may have been left, and old caps may be in poor condition.

Resistant building design

In areas where a hazard of subsidence has been identified, but the magnitude of the problem is not too great, buildings may be designed or modified to minimise the effects of subsidence. This may be achieved in several ways. The building itself may be designed as a rigid structure, often on a raft foundation, which will resist stresses imposed on it, or for larger buildings it may be designed with a degree of flexibility as a series of rigid sections to allow for the movement of the ground. In either case jacking points may be incorporated in the design to adjust the alignment of the building or structure after subsidence has occurred. Another approach is to isolate the structure from the ground movement by surrounding the foundation with easily deformable material such as loose granular material or expanded polystyrene. To some extent both methods may be applied to existing buildings by underpinning and surrounding the building with trenches of loose granular fill. A discussion of methods used can be found in the Department of the Environment commissioned report on mining instability in Great Britain (Anon, 1992b) and in text books on engineering geology and civil engineering (Bell, 1978; Bell, 1987; Waltham, 1989).

12 Made ground and landfill

INTRODUCTION

The long history of industrial development in the Wigan area has left an extensive legacy of human modification of the natural environment. The constraints imposed on planning and development by these modifications are dealt with fully in Volume 2 of this report ' A user's guide to Wigan's ground conditions'.

The distribution of made and worked ground map (Map 6) depicts :

1. the form of modification of the natural ground surface;
2. the distribution of different types of waste materials;
3. the distribution of major, engineered earthworks;
4. the distribution of 'disturbed' ground where modification of ground conditions of an unspecified nature is likely to have occurred.

FORM OF MODIFICATION

The natural environment can be modified by the addition of materials (tipping), effectively creating new anthropogenic, superficial deposits ('made ground'), or removal of material by excavation of the natural ground ('worked ground'). Tipping can take place either onto the natural ground surface or into excavations ('worked and made ground' but also termed 'fill'). Standard British Geological Survey terminology and symbols have been used to represent these forms of modification, which are illustrated in Figure 25.

Made ground

The representation of made ground on the map, shows areas of waste material with a clear topographic expression, deposited by man on the natural ground surface. They exclude civil engineering works, such as road and railway embankments. They represent deposits that were identified at the time of preparation of the maps. They were delineated by the use of documentary sources, including aerial photographs, topographical maps and boreholes.

However, in an area of long historical development like Wigan, made ground will be present beneath much of the urban area. Human activity has often created waste that, in many instances, was deposited at, or close to, its source of origin. Such waste is likely to include:

1. colliery spoil from small mines
2. building and demolition rubble (brick/stone/mortar etc.)
3. ashes and cinder
4. domestic waste

Construction often has taken place on the compacted rubble and deposits left by previous uses. Boreholes show that most of the urban areas of the Wigan district are underlain by a variable thickness of made ground. No attempt has been made to map these urban made ground deposits.

Worked ground

Worked ground includes areas where material is known to have been removed, for example in unfilled quarries and pits. Excavations made during the extraction of sand and gravel, sandstone, fireclay and brickclay are widespread in the Wigan area. They range in size from small, shallow 'brickfields' where the weathered sub-soil clay was collected by hand for local brick making, to large, mechanised quarries for sandstone e.g. Billinge Hill Quarry).

Quarries have been used as sites for the disposal of waste because, in general, they are easy to fill and restore and have few other uses. Many former quarries are now wholly, or partly, backfilled, and those that remain open are, generally, of a small size. Open quarries can pose potential safety hazards to the public, particularly if they are water filled or have unprotected vertical faces but they can provide valuable exposures of geological features, become sites of biological importance, offer recreational facilities (climbing) or, add to the scenic value of an area if properly managed on abandonment.

Worked and made ground

The combined worked and made ground category shown on the map comprises areas where the natural ground surface has been removed and the void partly or wholly backfilled with made ground. These deposits are sometimes known as fill. Mineral excavations have been used frequently for the disposal of waste materials. Quarrying operations in the Wigan area have been largely for brick clay, sand, gravel and sandstone. As these minerals have a comparatively low value, their winning does not warrant the removal of large volumes of overburden. Therefore, in Wigan, quarrying operations generally result in little waste material, and the infill of former quarries and brickpits is almost invariably with imported waste.

The largest area of worked and made ground in Wigan is that formed during opencast coal mining operations. This is a special case in that the volume of overburden is high and generally forms the whole of the infilling material.

CLASSIFICATION OF WASTE MATERIAL

Areas of made ground have been classified according to the type of waste material present in each site. A primary division has been made into:

1. Made ground — general waste (these are known collectively as landfills)
2. Made ground — mining waste

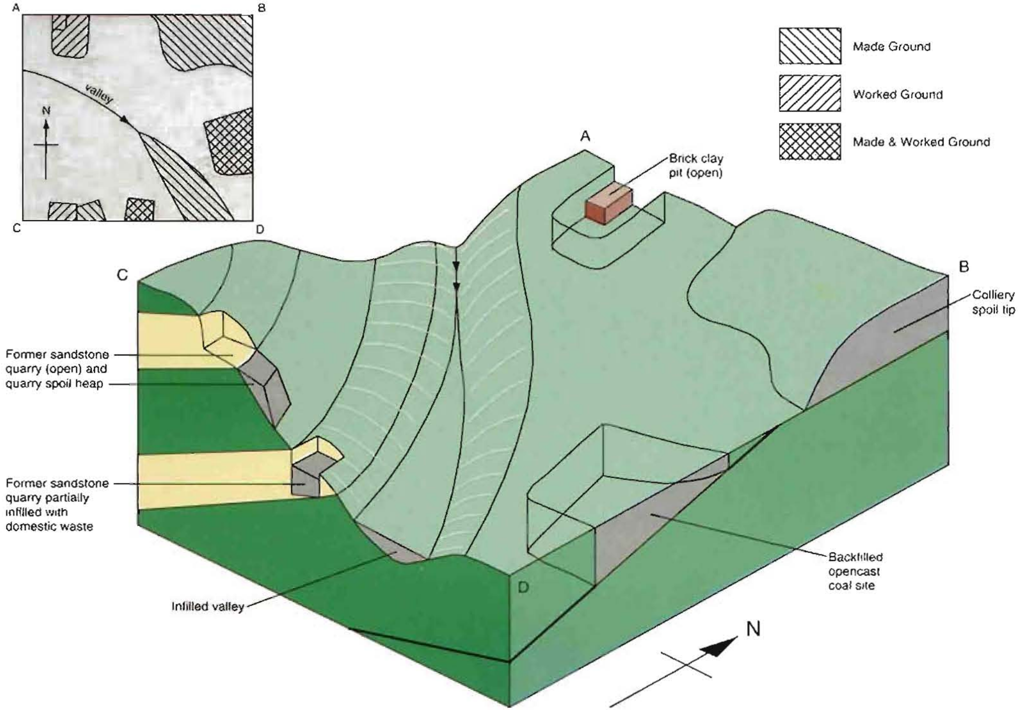


Figure 25 Illustration of the types of artificial superficial deposits in the Wigan area and the symbols used to indicate them on Map 6.

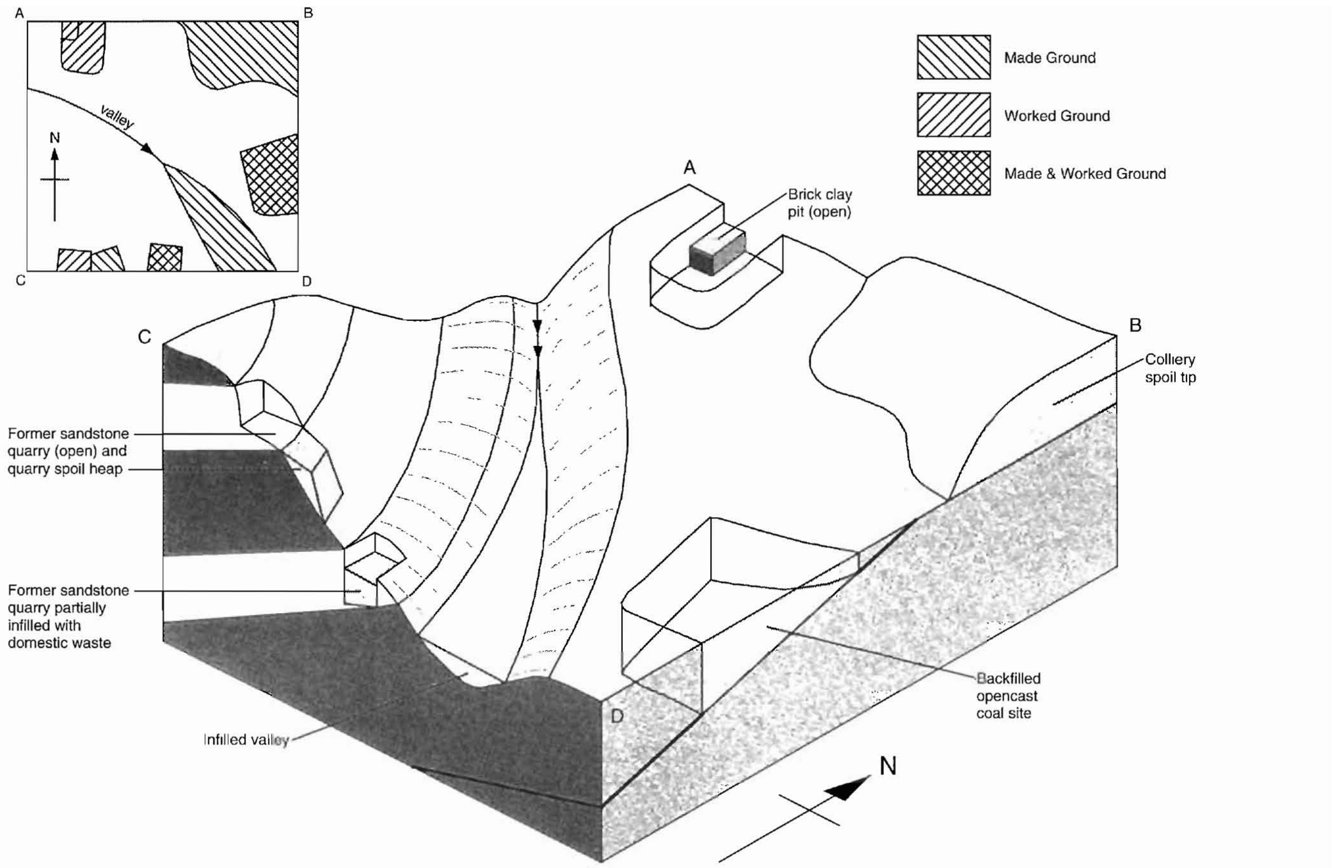


Figure 25 Illustration of the types of artificial superficial deposits in the Wigan area and the symbols used to indicate them on Map 6.

MADE GROUND — GENERAL WASTE

Landfilling is the term used to describe the deposition or tipping of a wide range of wastes on to available land. In this study, the term landfill is used to indicate repositories of waste materials which are not solely the product of coal mining activities.

Historically, very little control was applied to the siting of landfills. They tended to be located, for convenience and economy of disposal, in the nearest available space, hole or where infilling was required. Often they would be small, rapidly filled, covered and forgotten. This uncontrolled disposal included a wide range of active and inert waste materials from domestic and industrial sources. Problems caused by uncontrolled tipping included odours, air-borne litter, dust, noise, vermin, insects, and the generation of gaseous emissions and leachates. All of these contributed to a deterioration of environmental quality.

The generation of waste in urban areas continues and, whilst greater use is being made of alternative disposal methods, landfilling will continue to be an important means of disposal. An understanding of the geological environment has important implications for the selection of future landfill sites and for the handling of former landfill activities. Whilst many sites have been restored and developed, their presence still has implications for future planning and development.

Landfilling in Wigan

Examination of the available information relating to landfill in the Wigan area has identified 144 sites which have been classified as landfill. The sources of the information used were:

- Wigan Metropolitan Borough Council (Planning Department; Environmental Health Department; Consumer Protection Department)
- Greater Manchester Geological Unit, University of Manchester
- Greater Manchester Waste Disposal Authority
- British Geological Survey
- site investigation reports
- aerial photographs

The location and nature of sites is extremely variable, they include:

- engineered sites (Billinge Hill — [SD 527 013])
- former quarries (Wigan Road, West Leigh — [SD 648 013])
- infilled reservoirs (Farm Lane — [SD 605 067])
- infilled railway cuttings (Landgate Lane — [SD 575 015])
- mine shafts (Haigh Mine shaft — [SD 610 088])
- topographical depressions (Martland Mill — [SD 554 068])

The waste types found in these sites are typical of long-established industrialised areas and include domestic waste, sewage sludge, incinerator waste, general industrial waste, chemical wastes and inert materials.

Classification of landfill

The landfill sites, shown on Map 6 have been classified in terms of the waste types that they are **known** to contain. The classification has been applied using available existing data and no specific site investigations have been performed for verification. Therefore, the information should only be used as an indication of site composition and it is the responsibility of the user to ascertain the true conditions which exist at individual sites by means of more detailed investigation. The classification (Table 4), consists of three major types with the third being split into four subdivisions.

The classification for each site has been determined from the available records of the waste types contained. Details of these waste types (where known) are given in the study database. Generally, sites have been attributed to the first two categories where considerable knowledge about the tipping history is known through historical records and licence conditions.

Sites known to contain domestic, commercial, industrial and/or special waste

Where sites contain a combination of known waste types, they are assigned to the potentially more hazardous waste category. For example, a site containing 90% inert wastes and 10 per cent domestic waste is assigned to the 'domestic, commercial, industrial and/or special waste' category on the basis that domestic waste is a potentially greater environmental hazard than inert wastes.

Sites known to contain only inert waste

The term 'inert' as a description of waste has been extensively used historically to describe a wide variety of waste such as demolition waste containing wood, colliery spoil etc. These wastes are not completely inert because they contain materials which may slowly degrade to produce or release gas and leachate. Only sites which have accepted only materials such as non-organic soil, clay, sand, stone, concrete and bricks etc. should be classified as truly 'inert' sites. Therefore, whilst older sites have been classified as containing only 'inert' materials in this study, it is possible that some degradable materials may be present.

Site of uncertain composition

Sites where uncertainty exists about the nature of the contained waste materials are assigned to the third category. This has been split into four subdivisions. The first two of these subdivisions are used where unverified or incomplete information exists which suggests that either 'domestic, commercial, industrial and/or special waste' or 'inert' wastes may be present in a site. The third subdivision includes sites which, by virtue of their morphology, location and other information, are considered likely to contain only colliery spoil, though this is not proven. The fourth subdivision includes sites for which no information is available and they have been designated 'sites of unknown composition'.

The amount of information available for each of the sites is highly variable. Comprehensive information exists for modern sites but very little information is available for older sites especially those sites which are over 50 years old. Details of each site have been incorporated in the study database which will allow the user to make a preliminary assessment of an individual site or group of sites prior to detailed site investigation or consideration for planning and development. More details of the information contained in the database, and its structure, are given in Appendix I.

Table 4 Classifications used for distinguishing between landfills on Map 6 'The distribution of made and worked ground'.

Sites known to contain domestic, commercial, industrial and/or special waste Controlled waste types likely to generate significant quantities of gas or leachate.	
Sites known to contain inert wastes only, Sites that are unlikely to generate significant quantities of gas or leachate.	
Sites of uncertain composition	**Sites which possibly contain domestic, commercial, industrial and/or special waste**
	Sites which possibly contain inert wastes only
	Sites which possibly contain colliery spoil only
	Sites of unknown composition

Hazards associated with landfills

Problems associated with landfills include: odours, airborne litter, dust, noise, the occurrence of vermin, flies, gaseous emissions and leachates. Many have been dealt with through the implementation of environmental protection legislation which has resulted in improved landfill design, operation, monitoring and the retrospective fitting of control measures to existing sites. Current sites are governed by this legislation. For example, the site at Billinge Hill Quarry [SD 527 013] is an engineered containment site having facilities for the management of leachates and gas. The aim of the operators of present day sites is to minimise the environmental impact and allow the maximum reclamation of the land; for example, at Ince Moss Tip [SD 587 029], 70Ha is to be reclaimed and developed as a nature park.

Older sites, which predate current legislation and control, were not required to record much information and often little, if anything, is known about the sites. Therefore, it is these sites which pose the greatest potential hazard. They often contain unknown waste, there is an absence of monitoring and nothing is known about the current state of the wastes. Biodegradation of organic material in landfill generates methane and carbon dioxide. Landfill gas is the most important source of methane and carbon dioxide in Great Britain, with respect to potential hazards to man and structures. The potential for leachate and gas production will always be present within landfills which contain degradable organic or soluble materials. An appreciation of the geological environment of the site is important in assessing the severity posed by these materials since they are both hazards capable of migration through sub-surface materials.

No attempt has been made in this study to assess the relative risk posed by landfills. An earlier 'risk assessment' exercise was carried out by the Greater Manchester Geological Unit in an effort to prioritise Wigan Metropolitan Borough Council's investigation into old landfills. They assigned a value between 1 (lowest risk) and 5 (highest risk) to each of five factors including: type of waste, age of waste and proximity to development. These were then averaged to provide a final 'risk' factor. While useful as a first approach, this methodology does not take into account other factors such as site geology and leachate. Also, it cannot assign a risk value to the majority of sites in this area for which no information exists. Potentially, these may be the ones with the greatest hazard.

The characteristics of landfill gases and leachates, the hazards associated with them and the factors which influence the vulnerability of targets to landfill gas and leachate hazards are described in Chapter 13.

MADE GROUND — MINING WASTE

Colliery spoil heaps

Coal mining results in the production of large volumes of waste rock during the excavation of access tunnels, shafts etc. and from coal washing. The intensive mining activity in the Wigan area has caused a huge volume of waste material to be brought to the surface. During early mining operations the amount of waste produced was comparatively low because the seams worked were generally of high quality and, since payment was for coal not stone, the greater selectivity allowed by hand working was encouraged. Waste was mostly stowed within the mine or dumped on small tips close to the pit head.

Once mechanisation became commonplace the volumes of waste increased quickly, partly as a result of the growth of the industry and, partly because of the less selective methods of mining. Usually the waste was carried by tramway/railway, conveyor belt or aerial ropeway away from the minehead and tipped on adjacent land. To minimise the distance of transportation and the area of land required, tips were very high and steep sided, with slopes at the angle of repose of the waste material.

At the peak of the coal mining industry spoil heaps dominated the skyline of the Wigan area. As the industry has declined and the mines shut the spoil heaps have naturally revegetated, been reclaimed, or left as derelict land; 623 ha were classified as derelict in the survey of derelict land carried out by WMBC in 1993. Large areas of colliery spoil have been restored with the aid of 'Derelict Land Grants'. The end-uses of such restored sites include:

- public open-spaces
- recreation areas (for example, Three Sisters)
- industrial development
- engineered landfill sites
- farm land
- golf courses

Older colliery spoil heaps may contain a relatively high proportion of coal and carbonaceous material which, may catch fire and burn 'spontaneous combustion'. A number of spoil heap fires have been recorded in the past in the Wigan area (e.g. British Rails Ince Moss ballast tip), although none are burning at present. As well as the hazard of spreading to other property, tip fires can cause considerable nuisance due to smoke, fumes and dust, and lead to ground instability. However, the reddened and oxidised burnt shale may be suitable for use in, e.g. road construction.

In some instances the coal content of spoil heaps has been sufficiently high to make extraction of the coal economically viable. Coal-washing operations have been carried out at Bickershaw Colliery tip, Taylor Pit tip and Astley Green tip. Such operations are beneficial in that, as well as having economic benefit, they reduce the potential for spontaneous combustion.

Unreclaimed colliery spoil heaps are inspected annually by the Greater Manchester Geological Unit on behalf of the Mines and Quarries Inspectorate. They produce short summary reports on the condition of tips, with site locations plotted on 1:10 000 scale maps. The reports are principally concerned with safety aspects and potential hazards such as: condition of shafts (and relevant safety measures), erosion, signs of combustion, leachate, standing water bodies. Once tips are restored they are no longer the concern of the Mines and Quarries Inspectorate. Summaries of the Mines and Quarries Inspectorate reports are included in the study database.

The limits of tipping of colliery spoil have been determined from aerial photograph interpretation and old Ordnance Survey topographical maps. The recognition and delimitation of unrestored sites is relatively easy but for restored sites or sites which have been developed or built over boundaries are less easy to recognise.

Backfilled opencast coal sites

Modern opencast coal mining started as an emergency measure during the Second World War and the earliest workings in the Wigan area date from this period. A great number of small sites were worked until the late 1950s. There followed a break in opencast mining activity until the early 1970s, when the working of larger, deeper sites began.

Early sites were shallow and had a low overburden:coal ratio. They tended to be elongate along the strike and worked only one or two seams. Mining operations were not always systematically recorded; sometimes only a rough outline of the worked site is available and no records of the nature of backfill have been found.

Most sites were worked and restored quickly, usually within two years of commencing. It is unlikely that any significant volumes of foreign waste were imported to early opencast sites because of the pressure to work and restore sites quickly, and the relatively high costs of road transport at that time. Subsequent site investigations on these sites have not encountered any materials other than overburden.

Later sites (post 1970s) tend to be larger and deeper, with higher overburden:coal ratios. They tend to work multiple seams, including thin seams not previously economically viable. It is not uncommon for sites to produce an excess of material because the volume of excavated material is greater due to the increase in voids when broken up (bulking). In general, the infill of opencast sites is low in coal and carbonaceous material and comprises mostly mudstone/siltstone and sandstone of the site overburden.

Restored opencast coal sites have been put to a variety of uses. A number of early sites have been built over by residential developments (for example, in the New Houses and Hawkley areas of Wigan) while restoration of the recent Amberswood site has incorporated development of an engineered landfill site. Most have been returned to open park land or agriculture.

The locations of opencast coal sites have been derived entirely from British Coal Opencast Executive plans. Generally, these plans are at a scale of 1:2500 and should be consulted if more detailed boundaries are required. The plans are now held by the Coal Authority Mining Records Section in Bretby.

ENGINEERED EARTHWORKS

Engineered earthworks are defined as those areas where the movements (cutting or filling) of earth materials have been carried out in a controlled fashion to meet the requirements of a specified civil engineering usage. These are associated with:

- motorways/major arterial routes
- railways
- canals
- sites of industrial development

These areas have been identified from Ordnance Survey topographical maps and delineated by aerial photograph interpretation. Only earthworks associated with major construction sites have been identified. Other areas associated with minor operations may be present.

A number of sites where excess spoil from motorway construction has been tipped have been identified adjacent to the M6 motorway. It is not known whether the waste material (probably comprise till and bedrock lithologies) was compacted on tipping. These sites, which have been restored to agricultural usage, are shown as Engineered Fill on Map 6.

DISTURBED GROUND

Minor areas of 'disturbed ground' have been identified. These are areas where made ground or worked ground could not be differentiated but it is reasonable to assume that ground conditions have been changed from their natural state. It does not include areas where changed ground conditions are a product of industrial usage. For instance, early editions of Ordnance Survey topographical maps show the location of 'brickfields', areas where the weathered clay sub-soil was removed for brickmaking. Subsequently all have been built over. No records exist to indicate the depth of these workings and whether they were backfilled or levelled.

A large area of disturbed ground has been identified in Robin Park, Wigan. This area, which lies on the floodplain of the Douglas Valley, has a complex history of industrial usage, waste tipping, subsidence and flood protection works. Ground conditions in this area are likely to be disturbed. Similarly, Ince Moss has suffered subsidence, partial flooding, spoil tipping and re-working of spoil of such complexity that is not possible to distinguish the different activities individually.

13 Gases and leachates

GASES — NATURE AND HAZARDS

The hazards associated with the entry of methane, carbon dioxide and radon into buildings, construction operations and tunnels have received wide attention in Great Britain. Awareness of the hazards associated with methane derived from landfill has been raised as a result of fatal accidents, such as the gas explosion which destroyed a bungalow at Loscoe in Derbyshire. Landfill gas causes many more problems than methane and carbon dioxide emissions from natural sources.

Although nationally, relatively few examples have been reported of surface emissions of 'natural' methane and carbon dioxide, the Wigan area has a long association with natural methane emissions (Robinson and Grayson, 1990; Grayson and Robinson, 1995).

Methane

Methane is commonly produced, at the present time, by the decomposition of organic material, or formed over geological time, by the lithification of organic-rich material. Methane occurs principally in a free state in pores and cavities, adsorbed onto material such as coal and in solution in groundwater.

Methane emissions may represent both short and long term hazards, depending on the nature of the gas mixture, the geological conditions and the proximity and extent of building development. Methane is a colourless and odourless, low toxicity gas but can be a simple asphyxiant due to the displacement of oxygen. However, the greatest hazards posed by methane are those of fire or explosion. Methane forms an explosive mixture with air when the concentration is between 5 volume % (called the Lower Explosive Limit) and 15 volume % (Upper Explosive Limit), although concentrations greater than 15 volume % should not be considered safe. A flammable gas or gas mixture is potentially hazardous when it accumulates in a confined area (Hooker and Bannon, 1993).

Carbon dioxide

Carbon dioxide is a toxic, asphyxiating gas which is a stimulant to the respiratory and central nervous systems at high concentrations but may produce unconsciousness and death at very high concentrations. The physiological effects depend upon the degree and nature of exposure and may appear in both the short and the long term.

The long term exposure limit for carbon dioxide based on an eight hour reference period, is 0.5 volume % whilst the short term exposure limit, based on a ten minute reference period, is 1.5 volume %. Carbon dioxide, being denser than air, can displace air in hollows or confined spaces. High concentrations of carbon dioxide in soil gas may cause vegetation dieback (Hooker and Bannon, 1993; Appleton et al., 1995).

Radon

Radon is a naturally occurring radioactive gas produced by the radioactive decay of small quantities of radioactive minerals found in soils and rocks, Most radon remains in the rocks and soils but the small amount which escapes is quickly diluted in the atmosphere. Concentrations in the open air are normally very low and do not present a hazard. Radon may accumulate in poorly ventilated confined spaces in buildings and underground caves, mines, and tunnels. In some circumstances, concentrations of radon may be sufficient to cause concern if individuals are exposed to such levels for significant periods of time. The concentration of radon in a building primarily reflects the geological characteristics of the ground beneath the building, but is also affected by the sealing and ventilation of the building as controlled by its structural design, the heating and ventilation systems and the life style of the occupants.

Radon decays to form solid radioactive particles that may remain suspended in the air or settle onto surfaces or be inhaled by people, in which case they irradiate the lung and are considered to increase the risk of developing cancers of the respiratory tract, especially of the lungs. The radon risk to people who smoke is much higher. The short-lived decay products of radon gas account for approximately 51% of the average annual radiation dose and also cause the highest doses to individuals. It is estimated that radon may cause approximately 5% of deaths from lung cancer, that is, about 2500 per annum.

Oxygen deficient air

Oxygen deficient air is found commonly in old mines and tunnels but could occur in any enclosed space with high levels of carbon dioxide or methane, or in situations where oxygen has been adsorbed in acid mine water. A person entering an oxygen deficient atmosphere with only 6 to 10% oxygen will collapse within 40 seconds.

MIGRATION PROCESSES AND PATHWAYS

Once released from their source, gases may migrate through rocks or superficial deposits, if they are permeable, or along mechanical discontinuities such as open joints, fractures, bedding and fault planes. Migration is generally upwards from the source to the surface, unless the gas is trapped at intermediate depth. Gases migrate in response to pressure, temperature, concentration gradients or density effects. Drops in barometric pressure will lead to increases of gas flow whilst groundwater changes may cause gases to migrate. Conversely, gas migration may be temporarily stopped by waterlogging or freezing of the ground. Gases may also be dissolved in groundwater and may be released as groundwater enters natural or man-made voids, or as pressure conditions change. Hydrocarbon gas migrates from source rocks at depth towards the surface leading to accumulation in geological structural traps or, more rarely, seepages at the surface. Drilling or underground works may break into hydrocarbon traps leading to the release of gas or oil (Appleton et al., 1995).

GAS ACCUMULATION

If methane, carbon dioxide and radon accumulate in poorly ventilated enclosed spaces such as basements, buildings, foundations, caves, mines, and tunnels, they can reach high concentrations and may become a hazard. Buildings which contain basements or enclosed spaces may be particularly vulnerable to gas problems unless spaces are sealed or ventilation is provided. Migration pathways into the underfloor spaces and basement areas include cracks in floors, construction joints, cavity walls, wall cladding, ventilation ducts and gaps around gas, water, electricity, sewage and telecommunications service pipes entering a building, including sewers and the backfill surrounding pipes or cableways (Hooker and Bannon, 1993).

Volatile organic compounds (VOCs) produced by decomposition in landfill sites can also pose a threat. They may cause unpleasant smells and their build up in confined spaces can reach potentially toxic concentrations.

Tunnels are particularly prone to gas problems especially where methane or carbon dioxide dissolved in groundwater is released as a result of changing pressure. Dams and associated tunnels may be prone to gas migration and accumulation if organic matter accumulates behind a dam, or if limestone and oxidising sulphide rich rocks are brought together during or post construction, leading to the release of carbon dioxide gas (Hooker and Bannon, 1993).

NON-GEOLOGICAL SOURCES

Bacteriological sources

Bacteriological methane and carbon dioxide can be formed by the biodegradation of organic matter under anaerobic (oxygen-free) conditions. Bacteria which produce methane (methanogens), exist in many environments, including peat bogs, swamps, marshes, freshwater lakes, landfills, and organically contaminated groundwater. Marshy or peaty environments usually produce a gas predominantly composed of methane (50–85%) and carbon dioxide (4–15%, Swain, 1986). Minor amounts of methane may also be generated from sewage sludge, clayboard under foundations and slabs built on clay, compost heaps, fly tipping, cemeteries, slurry storage facilities, old cess pits, old wells and septic tanks.

Methane and carbon dioxide in soils

Soil contains living organisms and undecomposed organic substances as well as minerals, water and gases. The composition of gas in soils (soil gas) is influenced by a wide variety of factors including respiratory processes of plant roots, vegetation density, soil organic content, microbial activity, climatic factors and agricultural practices.

The background concentrations of methane in soil gas vary between 0.2 and 1.6 ppm, the latter being the mean concentration of methane in air. Methane concentrations above 0.1 volume % (1000 ppmv) are rarely encountered in soil gas in the absence of an identifiable source. In soils, carbon dioxide concentrations increase gradually with depth from about 0.03 volume % at the soil surface to 1 to 5 volume % below the plant rooting zone (Bolt and Bruggenwert, 1976; Fernandez and Kosian, 1987). Values of up to 0.7 volume % CO_2, with distinct seasonal variations, were reported from sandy calcareous soil (Reardon et al., 1979). Seasonal variations were also reported by Hoeks (1972) in an area where normal soil CO_2 was in the range 2 to 4 volume %.

Landfill

Landfill gas is the most important source of methane and carbon dioxide in most of Great Britain, with respect to potential hazards to man and structures. Landfill currently accounts for the disposal of around 90 % of UK refuse amounting to approximately 26 million tonnes per year. Over 50% of this refuse is composed of organic material which is potentially degradable. Modern trends have encouraged the development of large, deep landfills, in which the refuse can be densely packed and where conditions encourage the exclusion of air from much of the site.

Landfill gas is generated by the decomposition of the organic matter present in waste material under anaerobic conditions. Landfill gas consists of a very wide range of chemical compounds which can be divided into two categories:

1. major components — methane (CH_4) and carbon dioxide, (CO_2)
2. trace components — approximately one hundred volatile organic compounds (VOCs).

The proportion of methane and carbon dioxide depends primarily on the nature of the fill and the hydrogeological conditions; it also varies with time. Landfill gas consists predominantly of methane (commonly up to 65%) with CO_2 varying from 16 to 57%. The ratio of the two gases may be indicative of the source. In Great Britain, for example, carbon dioxide to methane ratios (per cent) are typically greater than 30% in modern biogenic gases and less than 10% in natural gases including mine gases. Other inorganic compounds such as hydrogen, oxygen, nitrogen, hydrogen sulphide and ammonia may also be present in low concentrations. The VOCs include vinyl chloride, benzene, toluene, alkanes, esters, organo-sulphur compounds and chlorinated hydrocarbons (Anon, 1989b; Hooker and Bannon, 1993).

Certain types of refuse (for example, building material) are often called inert but many types of material may be degraded by microbes or react in some way with other refuse. For example, the organic impurities in waste foundry sand, which has often been used as landfill, can be degraded anaerobically to yield methane gas; gypsum in plasterboard may be degraded by sulphate-reducing bacteria to produce hydrogen sulphide under anaerobic conditions. Building materials such as clayboard, timber, paper are composed of organic material and under anaerobic conditions may be degraded to produce methane and carbon dioxide (Hooker and Bannon, 1993).

A pattern of gas production is established in the waste materials as anaerobic conditions develop. The production of gas will continue until these conditions change substantially, for example, aerobic conditions return or all of the degradable waste is decomposed. Where conditions change within the landfill resulting in cessation of gas production, the potential for future gas generation may still remain.

More modern landfill sites have the potential to produce more gas than older ones because the composition of domestic wastes has changed with the proportion of organic wastes increasing. Modern landfilling practices are designed to optimise gas production so that it can be utilised.

Landfill gas, because of its composition, presents a number of hazards both on the landfill site and outside. Methane has a lower density than air and so it has the potential to escape through the surface of the landfill, the gas may also migrate by diffusion resulting from concentration gradients and also by advection because of pressure differences. Where upward migration is restricted, by water-logged soil cover or where a capping is present, lateral migration may occur (Figure 26).

GEOLOGICAL SOURCES

Coal and coal mines

Coal-bearing rocks appear to be the main source of methane and carbon dioxide emissions at the surface. Methane and carbon dioxide are produced as buried vegetation is converted to coal. Much of the gas is lost but some, especially methane is held by the coal in an adsorbed state. In the past, natural degassing of coal measures occurred, before the Wigan coalfield was fully developed there were reports of burning wells and of explosions which damaged houses (Robinson and Grayson, 1990; Hooker and Bannon, 1993). Coal seams are excellent gas reservoirs in terms of storage capability but poor producers unless disrupted by mining. Gas is only freely released from coal either in the vicinity of geological disturbance (Robinson and Grayson, 1990) or as a result of disturbance by mining (Creedy, 1990).

It is estimated that <25% of methane released by mining is removed by mine drainage techniques — the rest remains in the mine workings and surrounding strata, which act as a gas reservoir. Methane, and to a lesser extent carbon dioxide, emitted from working mines due to the high rate of disturbance, is emitted under controlled conditions and is therefore considered to pose a relatively low risk.

The surface emission of methane from coal seams and mine workings has been recorded in Great Britain at least since the mid-18th Century. A number of incidents have been encountered in which surface emissions of methane and carbon dioxide appear to be derived from old coal workings (Appleton et al., 1995). Methane may be a problem, especially in areas where coal seams approach the surface, due to degassing as the coal is fractured during extraction. The emission of gases continues after the mines are closed and, if dewatering and ventilation operations are stopped, the remnant gases in the mineworkings will accumulate. Problems with surface emissions appear to be mainly associated with closed, rather than working, mines.

Although the relationship between the rising water level in a mine and surface methane emissions is not proven, gas migration can be influenced, very significantly, by changing water levels. Coal extraction procedures are designed to reduce the risk of surface gas emissions following mine closure. The risk of surface gas emissions may be reduced by flooding because the water may seal the gas in lower workings and prevent its migration to the surface. However, the build up of gas concentrations and their pressure as old mine workings are flooded, combined with the presence of a suitable leakage path to the surface, could lead to surface emissions. In general, it is difficult to predict the severity of the gas hazard from individual mines due to the complexity of the geological and other factors involved.

It may be possible to reduce hazards from surface emissions of methane by exploiting gas held within the collapse zone, or within structural traps adjacent to old mineworkings. Further research is required to ascertain whether economic quantities of gas exist in, and adjacent to, the shallow coal workings which appear to be the main source of surface emissions (Appleton et al., 1995).

Coal mine waste

The property of carbonaceous material to emit gas over extended periods following extraction may have impli-

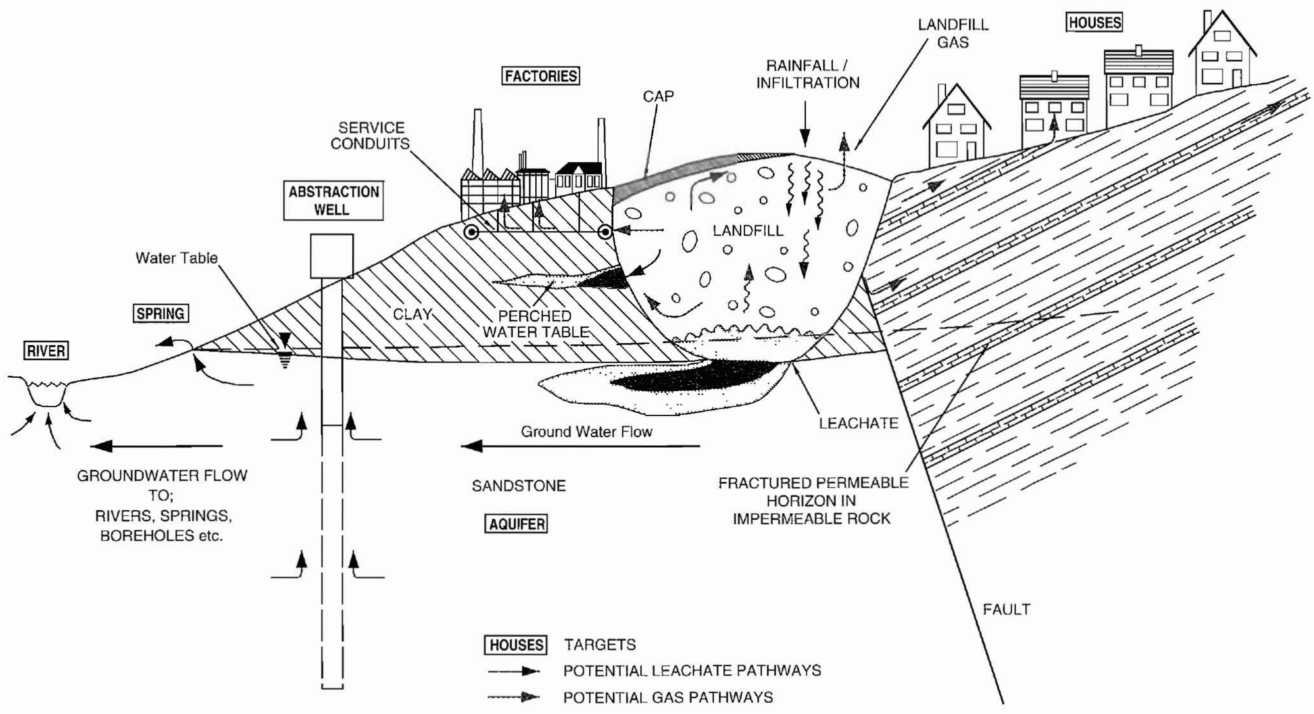


Figure 26 Potential pathways for the migration of landfill gases and leachates.

cations in connection with the use of colliery waste in land reclamation schemes (Creedy, 1989). Simple oxidation of a carbon source, such as coal, may produce CO and CO_2, although this may reflect high void volume or the reactive nature of freshly exposed surfaces of these materials.

Carbon dioxide from the action of acid waters on carbonates

Acid rain, acidic ground waters or sulphuric acid generated from the bacterial oxidation of sulphides can liberate CO_2 from carbonate rocks such as limestone or carbonate minerals in ore deposits or their wall rocks. Microbially-aided oxidation of pyrite in the compacted Namurian mudstone of the earth-fill embankment of the Carsington Reservoir, Derbyshire, produced sulphuric acid which reacted with the limestone drainage blankets to produce carbon dioxide which accumulated in site excavations with fatal results.

Methane and carbon dioxide in groundwater

Shallow groundwaters appear to have very low background concentrations of methane and carbon dioxide. However, these gases may dissolve in, and be transported by, groundwater from one place to another where they can be liberated when the groundwater flows into an excavation or void and confining pressure drops. Methane has a very low solubility at atmospheric pressure but at elevated pressures significant volumes can be held in solution in groundwater. The methane which caused an explosion in an underground pumping station at Abbeystead has been attributed to gas released from water (Hooker and Bannon, 1993).

Geological sources of radon

Radon is produced as a result of the radioactive decay of uranium minerals and their weathering products in rocks and soils. Natural uranium levels in the environment vary regionally depending on the local geology. Relatively high levels of radon are associated with two types of bedrock and superficial materials.

1. Areas underlain by rocks, and their weathering products, containing enhanced levels of uranium or radium. The principle rock types involved are granites and zones of uranium mineralisation, uraniferous black shales, and phosphatic sedimentary rocks.
2. Areas underlain by permeable rocks, superficial material, and their weathering products. The principle geological units in this association are limestones, permeable sandstones, sands and gravels. High radon is associated with the sandstone units within the Coal Measures (BGS, unpublished data).

Areas underlain by less permeable rock, superficial material and their weathering products, such as clays, shales and some less well cemented sandstones, especially where these have low uranium concentrations, are generally characterised by low radon concentrations in soil and houses. Peat and till are, in general, associated with low radon levels but the provenance of the till can be very important. Till, in general, depresses the radon levels expected from the underlying rocks, largely due to its impermeable nature.

SUSCEPTIBILITY CLASSIFICATION: 'NATURAL' METHANE AND CARBON DIOXIDE

Geology is the most important factor controlling the source and distribution of 'natural' methane and carbon dioxide. Methane and carbon dioxide emissions are associated with particular types of bedrock and superficial deposits of which the most important are coal, peat and buried organic material. Other organic-rich rocks and superficial deposits such as carbonaceous shale, oil shale, bituminous shale and organic-rich mud and silt are also potential sources. Rock strata and superficial deposits can be classified according to their susceptibility to gas seepages.

Low to moderate susceptibility

Materials from which the majority of recent surface gas emissions originate include the Carboniferous Coal Measures, and peat and organic material in buried watercourses, ponds, man-made reservoirs and tidal river sediments. Seepages of gases at the surface may result if water levels rise in abandoned coal mines, and suitable pathways, such as a faults, fractures, boreholes, tunnels, or shafts connect the mineworkings with the surface. Conversely, the risk of surface gas emissions may be reduced by flooding as this may seal the gas in lower workings and prevent its migration to the surface.

Major faults affecting low to moderately susceptible strata which occur close to the surface, or similar strata buried by permeable superficial deposits, are potential major migration pathways with a higher risk of surface and near-surface gas emissions. Where major Permian or Mesozoic faults affect buried strata, there is a higher risk of intersecting gas and oil in boreholes.

Low susceptibility

The Carboniferous Limestone and Millstone Grit contain thin coal seams and are the principal hydrocarbon gas source rocks in northern Britain. These strata do not crop out in the Wigan area but they could be intersected by boreholes or underground works and methane from them may be dissolved in groundwater, transported and liberated elsewhere. However, no records have been encountered of such problems in the Wigan area.

Where Carboniferous rocks are overlain by younger strata there is a risk of encountering gas in boreholes, underground workings or tunnels intersecting buried Carboniferous or younger strata which may contain gas. The risk is higher in structural gas traps, and near faults which intersect Carboniferous strata. In the concealed coalfields, the gas hazard may be greatest where redevelopment takes place over, or near, abandoned excavations (shafts, tunnels, boreholes) which have penetrated the impermeable strata over the Coal Measures and been imperfectly sealed. However, local occurrences of such problems have not been found.

FACTORS INFLUENCING VULNERABILITY TO LANDFILL GAS

The vulnerability of structures to landfill gas depends on a number of factors:

1. the nature and age of waste
2. the nature of containment, if any

3. the nature of remedial measures, if any
4. the presence of a driving force
5. the geological setting
6. the hydrogeological setting
7. the nature of the structures
8. the distance to the structures

In order to make an overall vulnerability assessment it is important that each of these factors is considered and assessed (Myers et al., 1994). Containment materials may reduce the probability of migration unless poorly constructed when they may exacerbate the problem by focusing the gas. A geological appraisal is important because favourable geological and pedological conditions may act to either contain the gas (impermeable clays), or act as a migration pathway (permeable sandstones, fractured rock, geological faults). Knowledge of the hydrogeological conditions is required because landfill gas may dissolve in groundwater and be released elsewhere or organic components of leachate may degrade during transport in groundwater to produce methane.

Man-made structures can also contribute to gas migration as they may provide permeable conduits. Examples are sewers, utility cables and pipelines, old mine workings and soughs. A summary of the controlling factors which must be considered in assessing the vulnerability of a structure (target) and an indication of the vulnerability associated with likely conditions for each is shown in Figure 27.

SUSCEPTIBILITY CLASSIFICATION: GEOLOGIC RADON POTENTIAL

Geologic radon potential mapping provides a guide to the level of radon emissions from the ground, and thus the potential risk of radon accumulation in buildings. It is especially effective where few radon measurements have been made in dwellings.

A geological unit is assigned to a radon potential class based on the assessment of the geological and pedological factors that influence the emission of radon at the surface, and, whenever possible, measurements of the concentration of radon in soil gas and houses. The reliability of the classification of a geological unit is relatively high where soil gas and house radon measurements have been made.

A general classification has been adopted for the 1:250 000 and 1:625 000 scale geologic radon potential maps of Great Britain (Table 5).

Where soil gas radon data are available, an estimate of the radon potential, and the estimated proportion of houses likely to exceed the Action Level, can be determined for each geological unit based on the soil gas radon concentration and soil-rock permeability (Table 6).

Insufficient information was available for the Wigan area to permit the assessment of the potential for radon

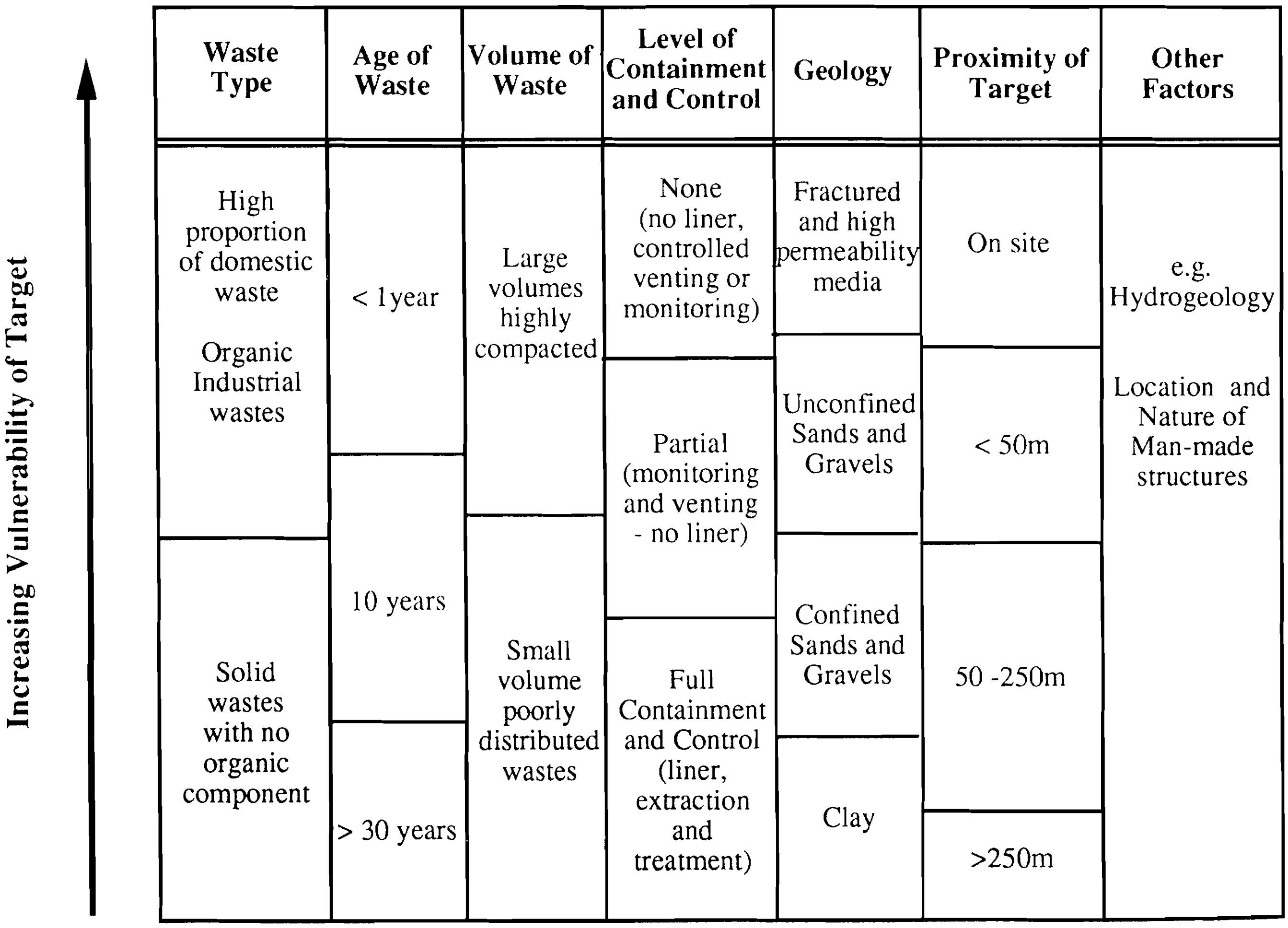


Figure 27 Factors to be considered when assessing vulnerability to landfill gas.

Table 5 Radon potential classification for The Natural Contamination Review of Great Britain (adapted from Appleton and Ball, 1995).

Radon Potential Class	Explanation
High	Ground susceptible to high levels of radon emissions
Moderate	Ground susceptible to moderate levels of radon emissions
Low-moderate	Ground susceptible to low levels of radon emissions but with sub-areas having moderate or high levels of radon emissions
Low	Ground susceptible to low levels of radon emissions
UC	Uncertain (insufficient data)

Table 6 Geologic radon potential classification based on concentration of radon in soil gas and rock/soil permeability (adapted from Appleton and Ball, 1995).

		Rock and Soil* Permeability		
		High	Moderate	Low
Estimated % Houses >Action Level	Radon potential class	Geometric mean radon concentration in soil gas (Bq/l)		
>10%	High	>19	>26	nd
3–10%	Moderate	9–19	19–26	nd
1–3%	Low	5–9	±10–19	±15–26
<1%	Very Low	<5	±<10	±<15

nd = no data
* = derived from Wetness Class in Soil Survey of England and Wales Bulletins

emissions from the ground so a soil gas radon survey was carried out following standard procedures (Appleton and Ball, 1995). The precision of individual radon determinations is dependent on the counting statistics; these vary from over 20% to 5% for 65% certainty.

Radon in soil gas concentrations were determined along 13 traverses at a total of 150 sites. The traverses were concentrated in the southern part of the Wigan area over those combinations of rock types and superficial deposit which were considered, on the basis of evidence from other areas in Great Britain (Appleton and Ball, 1995), to have higher radon potential. Geometric mean soil gas concentrations for each of the traverses and geological units are presented in Tables 7 and 8.

Recent work in other coalfield areas has indicated high levels of radon over faults and the importance of methane and carbon dioxide as carriers for radon. Therefore, carbon dioxide and methane were measured at most sites in order to provide background levels for these gases and to assess the importance of methane and carbon dioxide as carrier gases in methane susceptible areas.

The summary statistics for the whole data set are presented in Table 9. Radon in soil gas concentrations range from, not detected, (ND; set to 0.01 Bq/l for statistical calculations) to 71.9 Bq/l. The majority of the values are low with over 80% of the values recorded less than 10 Bq/l and over 50% of the values lie at 4 Bq/l or below. The arithmetic mean is 5.9 Bq/l with the median of 3.7 Bq/l. The geometric mean of 2 Bq/l illustrates the skewed nature of the data, as do the skewness and kurtosis factors.

Soil gas data were interpreted and radon potential assigned to each geological unit following procedures developed by Appleton and Ball (1995).

Each superficial and bedrock geological unit was assigned to a radon potential class using the classification given in Table 6 (based on soil/rock permeability, geometric mean soil gas radon concentrations) but also taking into account the maximum soil gas radon concentrations together with house radon data for analogous geological environments in Derbyshire (BGS, unpublished data). Most of the bedrock and superficial geological units measured during the survey are unlikely to give rise to elevated radon concentrations in houses.

Very Low and Low radon potential

Superficial geological units

The majority of the superficial units are assigned to the Very Low class, apart from glacial sand and gravels which may, in part, have Low radon potential if the superficial material and soil permeability are locally high. Glacial Sand and Gravels in some other areas have Moderate radon potential (Appleton and Ball, 1995) which may reflect higher permeability combined, in some cases, with higher uranium concentrations.

Areas mapped as till (boulder clay) and undifferentiated glacial material are characterised by soils with low to moderate permeability, which probably reflects the proportion of permeable sand and gravel in the till. Where till overlies Sherwood Sandstone, the combination of glacial till and sandstones sometimes seems to generate more radon than the two rock types separately and this may raise the radon potential from Very Low to Low, especially where the superficial cover is thin. The extent of ground underlain by Sherwood Sandstone covered with superficial material, in particular till, is probably larger than that affected by faults or underlain by Marine Beds (see below). However, the variability of results is high and, although locally elevated radon values may occur (for example, 18.7 and 36.7 Bq/l Traverse W13), this does not necessarily apply to the whole area underlain by this bedrock/superficial combination.

Bedrock geological units

Very Low to Low radon potential also characterises most areas underlain by bedrock geological units (Table 8). By analogy with the Derbyshire area, the Upper Coal Measures are assigned to the Low class, with higher radon potential expected over sandstone units. Although radon in soil gas measurements indicate Very Low potential for the Lower Coal Measures (Westphalian A), house radon data for the Derbyshire area suggest that Low to Moderate potential may be associated with those sectors of the Lower Coal Measures underlain by high permeability sandstones.

Marine Bands in shales may have a high radon potential as a result of elevated uranium content. However, these beds are usually only a few metres thick so only a relatively small area potentially is, affected. The geometric mean concentration (7 Bq/l) for the Wigan survey indicates only a Very Low potential for ground above the mapped sub-crop of these Marine Bands. However, the maximum

Table 7 Summary of radon in soil gas concentrations for Wigan survey.

	Radon concentration (Bq/l)					
No. of sites	Range	Geometric mean	Geological Formation	Overburden	Overburden (thickness)	Traverse Number (W)
3	0.8–1.5	2.2	Westphalian A (LCM)	Till	<5 m	1
6	1.7–5.2	2.8	Westphalian A (LCM	None	<5 m	1
10	0.4–17.8	4.1	Westphalian B (MCM)	None	<5 m	1
10	ND–10.3	1.2	Westphalian A (LCM)	Sands	<5 m	2
3	4.1–20	7.1	Sherwood Sst (Pebble Beds)	Till	<5 m	4
8	0.5–7.5	3.0	Sherwood Sst (Pebble Beds)	None	<5 m	4
3	ND–20.4	n.a.	Manchester Marl	Till	30 m–40 m	5
10	ND–5.8	1.5	Collyhurst Sst	Till	30 m–40 m	5
12	0.1–6.3	1.9	Sherwood Sandstone Group	Glacial Laminated Clays	?	6
12	ND–71.9	0.9	Sherwood Sandstone Group	Glacial Laminated Clays	About 30 m	7
10	ND–5.6	0.7	Sherwood Sandstone Group	Glacial Gravel	About 30 m	8
8	0.4–9.3	2.6	Sherwood Sst (Pebble Beds)	Glacial Sands and Gravels	<5 m	9
11	ND–5.1	0.3	Ravenhead Rock	None	About 30 m	3
9	0.5–14.1	4.3	Sherwood Sandstone Group	River terrace	About 10 m	10
10	2.0–25.4	7.8	Sherwood Sandstone Group	Glacial Sands and Gravels	About 30 m	11
3	4.9–13.6	7.3	Duckinfield Marine band	Till	<5 m	12
9	2.1–17.2	6.5	Westphalian B (MCM)	Till	<5 m	12
10	ND–36.7	0.5	Sherwood Sandstone Group	Till	?	13
3	23.9–34.4	29.6	Fault zone	None	<5 m	1
150	**ND–71.9**	**2.0**	**All data**			

ND = not detected
n.a. = not applicable (very variable)
LCM = Lower Coal Measures
MCM = Middle Coal Measures

Table 8 Radon potential of superficial and bedrock geological units in the Wigan area.

Geological unit	Soil/rock permeability (Soil Wetness Class in brackets *)	Geometric mean soil gas radon concentrations (Bq/l)	Radon potential
SUPERFICIAL			
Peat	Low (6)	nd	Very Low
Alluvium	Low (4–5)	nd	Very Low
River Terrace Deposits	Moderate to low (2–5)	4	Very Low
Late-Glacial Flood Gravels	Moderate (nd)	nd	nd
Shirdley Hill Sand	Moderate (nd)	nd	Very Low ?
Glacial Sand and Gravel	High to low (1–4)	1, 8	Very Low–Low
Glacial laminated clays	Low (nd)	1, 2	Very Low
Till (Boulder Clay) and glacial undifferentiated	Low to moderate (2–4)	<1, 2	Very Low (? Low over Sherwood Sst)
BEDROCK			
Sherwood Sandstones	High (1–2)	3	Very Low
Sherwood Sandstone Pebble Beds	High (1–2)	3, 7	Very Low–Low
Upper Coal Measures	Low (4); sandstone high)	nd	? Low
Middle Coal Measures	Low (4)	4, 7	Very Low–Low
Middle Coal Measures: marine bands	Moderate (nd)	7	Very Low–Low
Lower Coal Measures: sandstones (Ravenhead Rock)	High to moderate (1–3)	<1	Very Low
Lower Coal Measures: undifferentiated	Low (4)	1, 2, 3	Very Low
Faults	High (nd)	30	High

nd = no data available
* = Soil Survey of England and Wales Bulletin No. 12

Table 9 Summary statistics for all radon measurements.

	Radon Bq/l
Mean	5.9
Standard Error	0.7
Median	3.7
Geometric Mean	2.0
Mode	0.01
Standard Deviation	8.6
Kurtosis	24.4
Skewness	4.1
Range	71.9
Minimum	0.01
Maximum	71.9
Count	150

value of 13.6 Bq/l suggests that some sectors underlain by Marine Bands may have Low potential.

High radon potential

High radon potential is assigned to faults and fractures. These are generally narrow linear features, so relatively small areas of ground, potentially, will be affected. It is not possible, without detailed site investigations, to determine which, if any, of the faults not surveyed have high levels of gas flow. Those faults which do have significant gas flows may also produce high CO_2 levels and possibly also high methane.

LIMITATIONS OF RADON POTENTIAL CLASSIFICATION

The categorisation of a group of rocks or superficial deposits as having known, or suspected, enhanced potential for radon emissions does not imply that there is a radon problem in buildings built on these geological units. That would depend on whether pathways, locations for accumulation, and protracted exposure occur. Therefore, the radon potential class does not give any direct guide to the level of radon in individual buildings or cavities. However, there is, in general, a higher likelihood that radon problems may occur at specific sites within areas with Low-Moderate, Moderate or High radon potential.

The radon potential information can be used to identify priority areas for monitoring of radon in buildings and identify geological units for which additional information on radon may need to be obtained. The radon potential assignments must not be relied upon as a source of detailed information about specific areas, or as a substitute for site investigation, ground survey or house radon monitoring. Appropriate professional advice should be sought and a ground survey or site investigation commissioned, if necessary, to verify that ground conditions are suitable for any particular land use or development. Monitoring of radon levels in buildings should be carried out, if appropriate, to decide whether any remedial action is needed.

The data on which the radon potential assignments are based are not comprehensive. Localised or anomalous features may not be represented. Small areas of lower or higher radon potential are likely to occur within areas given a specified classification because of the occurrence of small units of contrasting lithology and permeability or unmapped shear and fracture zones.

LEACHATES

Rain water, groundwater or other water, such as that contained in the waste at deposition or which percolates through a landfill, will become enriched in the soluble components contained within the waste or resulting from its degradation. The resulting leachate can be a highly complex and variable mixture of inorganic, organic, microbial constituents and suspended solids in an aqueous medium. Many of the components are potentially hazardous to human, animal and plant life and leachate constitutes a hazard if exposure exceeds critical levels (Anon, 1992b).

The quantity and quality of leachate depends on a large number of factors, including the amount, composition, density, age of the waste, the hydrology of the site and the meteorological conditions (Anon, 1986a; Lu et al., 1985). The components and ranges of concentrations commonly found in landfill leachates are listed in Table 10. Generally, sites containing only inert waste are unlikely to produce significant quantities of leachate but those containing degradable, industrial, chemical and unknown wastes may produce leachates. In contained landfills, leachate is controlled and treated so that there is very little threat of uncontrolled migration away from the landfill. However, at the majority of sites control and treatment processes are not in place. At these sites, there is the potential for the build up and migration of leachates. Potential targets for leachate are considered as receptors which, when contaminated may pose a direct or indirect threat to human, animal and plant health. For leachates, these vulnerable targets include surface water courses, springs, foundations, ponds, lakes and groundwater resources (Parsons, 1985).

FACTORS INFLUENCING VULNERABILITY TO LANDFILL LEACHATES

Except where a build up of leachate is so great that it overflows the site, migration of leachate is through the subsurface. Many factors can play a role in controlling leachate migration and are important in assessing the specific vulnerability of targets to pollution. The physical, chemical and biological implications of each need to be considered in order to assess the overall vulnerability of a target.

Important factors include:

- the nature of engineered containment material
- the nature of natural soil cover
- the nature of bedrock
- the nature of superficial deposits
- the depth of the unsaturated zone
- the hydrogeological setting
- the distance to the target
- artificial influences, for example, mineworkings, soughs

The National River Authority, which has a responsibility to monitor and protect the quality of surface waters and groundwater under the Water Resources Act 1991, has adopted a policy and practice for groundwater protection (Anon, 1992b). This defines the criteria which have been developed for assessing vulnerability. These criteria recognise the fact that vulnerability is higher in some hydrogeological, geological and soil conditions than in others. For example, low permeability media, such as compacted clays, offer greater protection than high permeability media, such as fractured sandstone. A summary of the most important factors which need to be considered when assessing vulnerability to landfill leachates is shown in Figure 28. An indication of the level of vulnerability resulting from different conditions and situations likely to be encountered is given for each controlling factor.

Table 10 The range of concentrations of the constituents of leachate from landfills containing municipal wastes (Anon, 1986b ; concentrations in mg/l).

Component	Range domestic	Fresh wastes	Aged wastes
pH	3.5–8.5	6.2	7.5
Chemical Oxygen Demand (COD)	50–90 000	23 800	1160
Biochemical Oxygen Demand (BOD)	5–75 000	11 900	260
Total Organic Carbon (TOC)	50–45 000	8000	465
Total coliform bacteria (cfu/100 ml)	0–10		
Iron	23–5500	540	23
Zinc	0.4–220	21.5	0.4
Sulphate	25–500		
Sodium	0.2–79	960	300
Total Volatile Acids	5–27 700	5688	5
Manganese	0.6–41	27	2.1
Faecal coliform bacteria (cfu/1000 ml)	0–10		
Ammonium	0–1106		
Ammonia	0.1–2000	790	370
Total phosphorous	0.1–150	0.73	1.4
Organic phosphorous	0.4–100		
Phosphate (inorganic)	0.4–150		
Nitrate	0.4–45	3	1
Chloride	30–5000	1315	2080
Sodium	20–9601	960	1300
Magnesium	3–15 600	252	185
Potassium	35–2300	780	590
Calcium	0.1–36 000	1820	250
Nickel	0.05–1.7	0.6	0.1
Copper	0.001–9	0.12	0.3
Lead	0.001–1.44	8.4	0.14

Increasing Vulnerability of Target (↑)

Waste Type	Level of Containment and Control	Nature of Soil Cover	Drift Deposits	Solid Geology/ Hydrogeology	Depth of Unsaturated Zone	Distance/ Travel Time to Target	Other Factors
Co-disposal of liquid wastes Domestic waste Hazardous industrial wastes	None (unlined and uncapped with no controls)	Shallow Coarse textured Low attenuation capacity	High proportion of sand and gravel High permeability	Fractured and faulted formations with high permeability including ; limestone sandstones and clay	Shallow or fissured Perched Water Tables	Target on site	e.g. Underground mine workings and soughs etc.
	Partial (incomplete enclosure of wastes or some remedial controls)	Moderate attenuation capacity and permeability		Porous media; sandstone		50 m or 50 days	
Inert wastes					Deep with low permeability	400 days	
	Full Containment and Control (cap, liner, leachate and gas controls)	Low permeability High attenuation capacity	Low permeability Clay	Low permeability mudstones clays		Several kilometres/ Aquifer catchment	

Figure 28 Factors to be considered when assessing vulnerability to landfill leachates.

14 Previous and present industrial land uses

INTRODUCTION

All human activities on, over, or within the ground will alter its natural state to a greater or lesser degree. These activities may be pastoral, agricultural, industrial or recreational but they will all add to, remove from, or alter in some way the natural environment. Where material has been added to the environment and caused the environment to be degraded with regard to a particular current or future use then this process may be regarded as 'contaminative' with respect to that use. However, the use of the term contaminative is a judgement which is dependant on the observer and the, often unspecified, future use. The addition of nitrogenous fertiliser may ensure a positive gain to agricultural crop yields but may also been regarded as a 'contamination' by others because it may increase the nitrate levels in the public water supply to the detriment of some consumers.

In the Wigan Metropolitan Borough past industrial activity, in some areas, has left a legacy of land which has suffered the addition of artificial and natural materials which are alien to the local environment and may be regarded as 'contaminants' with regard to some current land uses. There is currently much concern about identifying and delineating areas of 'contaminated ground' but there is little consensus on what constitutes 'contamination'. The lack of agreement is due to the reasons discussed above and because public reaction to land termed 'contaminated' might result in planning blight of affected land. Therefore, it has been difficult to portray, in map form, the problems that past land use have left in the Wigan area.

The site history is the principal factor that determines whether a site is likely to have been adversely affected, or not, for current and future use. The portrayal of previous and present industrial uses, in map form, is intended to indicate areas where changes to the ground, which may be prejudicial to common, current and proposed land uses, could have taken place and may still be present. Knowledge of the previous use of an area is essential before designing a site investigation prior to the development of the site. It is necessary to indicate what specialist services are required to determine if chemical or biological factors are present which might be prejudicial to the intended future use.

Industrial sites which are known to have been affected by 'contaminative' processes may not be uniformly affected by that process. The deleterious effects may be restricted to small areas within the site or the site may have been decontaminated and restored since that time. In view of the potential hazard posed by such sites, great care must be taken with respect to the health and safety of the site investigation personnel and members of the public and it is important that the investigation of such sites is carried out by experienced specialist contractors in accordance with the current best practices.

SOURCES OF INFORMATION

Two pilot studies of methods of identifying potentially contaminated sites have been carried out. In each of these studies most sites were identified from two sources of information — old Ordnance Survey topographical maps and existing registers held by the local council. In a pilot study by Bentley and Rice (1992) each of 170 sites was identified from these sources; none of the other sources recommended, at that time, by the Department of the Environment produced any significant extra information.

In a pilot study of potentially contaminated land in Cheshire (Anon, 1990b) it was found that, while the Ordnance Survey 1:10 560 (6″) or 1:10 000 scale maps provided 'the optimum blend between ease of use and the amount of information available', in the built up areas of Lancashire, the County Series 6″ maps showed significantly less information. In two selected sample areas, it was found that the 6″ maps often only identified sites by the general term "works", whereas the 25 inch to one mile (1:2500 scale) maps gave a specific site name (e.g. 'Albion Iron Works').

A similar comparative exercise was carried out for the two 1908 edition 1:2500 scale County Series sheets covering the centre of Wigan. In this area, the 1:2500 scale maps identified a few small sites not labelled on the 1:10 560 scale maps. However, working at the larger scale for the whole of the Wigan area would have required much greater effort than the small amount of additional data justified. Despite this it is recommended that all scales of available maps should be consulted at the pre-ground investigation, desk study stage for developments in urban areas with a history of industrial activity.

The primary sources of information used for this study were the Six-inch (6″) to One Mile (1: 10 560 scale) County Series or 1:10 000 scale National Grid topographical maps. The following editions were consulted:

1849–First Survey — County Series 6″

1909 — Country Series 6″

1929–30 — County Series 6″

1956 — National Grid 6″

1980–94 — National Grid 1:10 000

Field maps of the Second Land Utilisation Survey of Great Britain carried out in 1961–1967 by Kings College, London (Coleman and Shaw, 1980) were also consulted. These show, among other things, the distribution of different categories of industrial land usage at the time of survey. The categories are not the same as those adopted for the purposes of this study.

CLASSIFICATION OF INDUSTRIAL USE

Map 7 shows areas of industrial use, distinguishes between past and present use and divides them into two classes:

1. Industries which may have been 'contaminative'.
2. Sites of general industrial use where the potential for contamination is slight.

Those areas identified as potentially contaminative are assigned to 16 categories of industrial use based on categories of use quoted in the following documents:

- The Department of the Environment and The Welsh Office joint circular 21/87. — Development of Contaminated Land (Anon, 1987a)
- Registers of land which may be contaminated: A Consultation Paper, The Department of the Environment, May 1991 (Anon 1991).
- Draft Regulations contained in proposals for the Environmental Protection Act 1990 Section 143 Registers issued by The Department of the Environment, July 1992 (Anon, 1992c)

The categories used have been adapted to reflect the range of industry in the Wigan area. Landfill sites are shown on Map 6 and the potential hazards associated with landfills are discussed in the Chapters 12 and 13. Sites of potentially contaminative uses are identified by number and letter code which relate to entries in the study database (Chapter 4, Appendix I).

IMPLICATIONS FOR PLANNING

Map 7 and the associated database are not definitive documents, and must not be taken as depicting the full history of a particular site. They are intended, primarily, as a guide for planning, by indicating areas where industrial use has occurred and the nature of that use. Also, they indicate areas where a detailed study of the site history, followed by specialist site investigation, may be necessary. At present no statutory procedure for carrying out such work exists. It is suggested that such investigations be carried out following discussion with officers of the Wigan Metropolitan District Council and follow the guidelines given in the Department of the Environment's 'Guidance on preliminary site inspection of contaminated land' (Anon, 1994b), The British Standards Institution's 'Draft for Development — Code of practise for the identification of potentially contaminated land and it's investigation' (Anon, 1988b) and the Report of the Site Investigation Steering Group of the Institution of Civil Engineers especially part four — 'Guidelines for the safe investigation by drilling of landfills and contaminated land' (Anon, 1994c).

LIMITATIONS TO USE OF MAP 7

Although care has been taken in the preparation of this map, not every potentially contaminative industrial use will have been identified. The project has consulted those records available to it but it is anticipated that other, unknown, records, which may contain information on other former industrial sites, may exist which were not available. There may be other sites, formally used for industrial purposes, for which no record was made or survives.

In previous studies topographical maps have proved to be the most prolific and valuable source of information (Bentley and Rice, 1992). However, topographical maps represent only information available at their time of preparation. Some industrial usage is short term and it is possible that sites may have been used and abandoned in the intervals between re-survey. However, most potentially contaminative industrial uses in the Wigan area are related to the thriving industrial economy at the turn of the century, and two closely spaced map editions (1909 and 1929) are available from this time.

In previous studies of potentially contaminative industrial uses it has been found impractical to consider sites smaller than 0.5 hectares in size. Although no size limit has been applied in this study, smaller sites have only been identified in rural areas, where they have stood out against the contrasting background activity. In densely developed, urban areas where sites are close together, individual sites have frequently been unrecorded. It is prudent to investigate the site history of all sites in well established urban areas, even if they have not been identified as being associated with a previous industrial use.

Areas shown on the maps are, in general, defined by the maximum area of occupation of the industrial use. Contamination of a site will vary widely depending on the nature of the industry and the practises carried out on the site. It may be present as general contamination across a whole site, or may be concentrated in small pockets of significant contamination within a generally uncontaminated site. The designation of an area to a specific past use does not, necessarily, imply that the area is contaminated, in whole or in part, or, if once contaminated, that it has not subsequently been decontaminated.

A particular problem relating to the identification of former industrial land use in the Wigan area is that of collieries. Early collieries tended to have comparatively short life spans. Many were developed and abandoned in the interval between the publication of maps of successive topographical surveys. Many of the smaller pits had been abandoned prior to the first 1849 survey. No attempt has been made to identify all of these small ventures. Map 1 shows the location of known shafts, and the possibility should be considered that surface buildings may have been associated with these shafts and have not been recorded and, therefore, are not entered on the past industrial uses map.

Later, colliery complexes were often unplanned collections of pit-head gear, allied buildings (stores/bathhouses/offices/workshops etc.), storage and stockpile areas, washing plants, transport links, sidings and waste tips. Therefore, the boundaries drawn around complexes of this nature are only approximate and the detailed disposition of buildings and activities within a site should be looked for in the pre-ground investigation, desk study, stage of development.

POTENTIALLY HARMFUL ELEMENT CONTAMINATION

Chemical elements occur in the environment which under certain circumstances can be harmful to the health of living organisms, including plants, animals and people, or cause interference with the ecological systems of which they form a part. For example, in humans and other animals, cadmium (Cd) may progressively, and irreversibly, impair kidney function. Exposure of young children to even quite modest amounts of lead (Pb) can, in the long term, permanently impair mental functions. High concentrations of zinc (Zn) in soil are known to inhibit plant growth, and in animals cause severe anaemia whereas excess zinc has been implicated in the onset of oesophageal and stomach cancers in people. High concentrations of arsenic (As) in the diet can cause severe skin problems, whilst chronic exposure to low doses of arsenic may lead to the development of lung and skin cancer. Inhibition of plant growth (phytotoxicity) may be caused by elevated concentrations of nickel (Ni), cobalt (Co) and chromium (Cr) in soils.

The term 'potentially harmful element' (PHEs) is used to describe chemical elements such as arsenic, cadmium, and lead, in preference to 'heavy metals' or 'potentially toxic elements' in order to avoid arousing concern caused by use of the potentially emotive term 'toxic' and because it is also consistent with the terminology used in the Environmental Protection Act (Anon, 1990c). In this report, therefore, potentially harmful elements (PHEs) are used to describe both non-essential, potentially toxic, elements such as arsenic, cadmium and lead as well as elements such as copper (Cu) and zinc (Zn) which are essential for plants and animals at low concentrations but may be toxic at higher concentrations.

The adverse effects of potentially harmful elements depend on the type and extent of exposure and on whether they are ingested, adsorbed through the skin (humans and other animals) or the roots (plants), or inhaled in dust. Ingestion may be by hand to mouth contact, which especially affects young children, by drinking contaminated water, or by eating plants that have either adsorbed PHEs through the root system or are contaminated by soil containing elevated concentrations of PHEs. Eating vegetation contaminated by soil is the major ingestion route for animals such as cows and sheep. Dust from contaminated soil or waste and spoil heaps, for example, may be ingested by inhalation of wind-blown dust.

The occurrence of elevated concentrations of these elements in the environment does not necessarily indicate there is a significant risk, as this will depend on a number of factors including their chemical form, concentration, behaviour, and the extent to which they may be taken up by living organisms, the size of the particles in which the elements occur, soil or water acidity (pH), the type of vegetation cover and the root characteristics of the plants, the extent of exposure and the dose received. Very high concentrations may not pose a risk as the element may be in a chemical form that is relatively immobile, insoluble in water and not absorbed by plants or by humans and other animals if ingested. Conversely, some elements become more available in acid waters and soils and therefore may be adsorbed by plants or mobilised and transported in surface and ground waters (Appleton, 1995).

Contamination sources

Elevated concentrations of PHEs in soils, dust, surface and ground water, or dust may arise from:

1. artificial sources, for example emissions from past or present industrial activity (such as steel works or coal mining), solid or liquid wastes and sewage sludge.
2. natural sources, for instance some types of rocks or above metalliferous ores

Geochemical signatures of man-made (anthropogenic) contamination, including that resulting from industry and other contaminative uses specified in the 1991 consultative document for Section 143 Registers, were summarised by Appleton (1995).

Data Sources

The British Geological Survey, Geochemical Survey Programme stream sediment, soil and surface water geochemical data for the Wigan area have been assessed in relation to:

1. Local background levels in sediments and soils
2. Upper limits of background concentrations in stream sediments established by the Department of the Environment, Natural Contamination Review (Appleton, 1995)
3. CEC Maximum Admissible Concentrations (MAC) in drinking water
4. sources of potential contamination related to present and past industrial use, made ground, backfilled areas and mining. (Maps 6 and 9)

Where no guideline exists (for example, for Ni), the distribution of the samples with the highest concentrations (>90 percentile) has been assessed.

The objective of the assessment was to identify the level and extent of contamination by potentially harmful elements (including Cd, Cr, Cu, Ni, Pb and Zn) derived from both natural sources and past industrial uses of land.

Stream sediment geochemical data

A large part of the Wigan area is urban and unsuitable for sample collection Therefore, only 66 samples were collected and the average sampling density is relatively low (1 per >4 km^2). Metal concentrations detected in stream sediments are high compared with average concentrations in Northern Britain (Table 11). Indications of contamination were recorded at most of the sites, which is typical of urbanised areas. The upper limit of back-

Table 11 Statistical summary of stream sediment data from Wigan area. All values in ppm.

Element	Northern Britain Range	50%	90%	Wigan area Range	50%	90%	'Contamination Level' ①	WMB n>'Contamination Level' ②
Pb	0–9993	40	110	28–690	89	292	120	30
Cd	0–54.1	0.5	2.1	0–9.5	0.7	3.9	4	7
Zn	0–8745	145	385	23–1365	246	742	400	19
Cu	0–1042	19	46	7–407	59	134	110	13
Ni	0–8400	45	98	23–203	66	98	98	9
Cr	0–16 225	104	260	0–410	113	200	300	2

① Upper limit of background (DOE Natural Contamination Review).

② Number of samples in Wigan MBC exceeding ①.

ground concentrations is exceeded in 13 to 30 samples for Cu, Zn and Pb and in 2 to 9 samples for Cd, Cr, and Ni. Many high Fe, Mn, Cu, Ni and Zn concentrations which were recorded in the Standish–Astley Green area appear to be related to contamination from coal mine spoil. To the south-east of Ashton-in-Makerfield [SJ 5944 9843], high Cd, Cu, Ni, Pb and Zn concentrations may indicate contamination from a nearby sewage works.

Soil geochemical data

Data were available for 75 soil samples within the Wigan MBC. Considering the level of urbanisation, the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) threshold concentrations (Anon, 1987b) are exceeded in relatively few samples (Table 12). Direct comparison of soil concentrations for Cd, Cr, Cu, Ni, Pb, Zn with ICRCL threshold 'trigger concentrations' is not possible because the Geochemical Survey Programme data are for the <150 μm size fraction of sub-surface soils taken at a depth of about 600 mm whereas the ICRCL soil contaminant trigger concentrations apply to total soils (air-dried, crushed, split (but not sieved) and ground prior to analysis). Other limit values, such as the maximum permissible concentrations of potentially toxic elements in soil (mg/kg dry solids) at, or above, which application of sewage sludge is not permitted (CEC Directive 86/278/EEC) are based on total soil samples taken to a depth of 250 mm (and not less than 100 mm). Sub-surface soils better indicate natural background concentrations and are not good indicators of surface contamination, unless there has been a substantial migration of contaminants down the soil profile. The relatively few samples with Cu, Ni and Zn concentrations above the ICRCL soil contaminant guideline concentrations are associated with mine spoil and made ground. No other specific sources of industrial contamination are indicated by the soil samples, although areas with significant levels of contamination could have been missed by the low density of sub-surface soil sampling. For example, a site investigation at Westwood Power Station found a number of small pockets containing low-levels of contamination, principally related to the disposal of waste.

The highest Pb value (7643 ppm) was recorded in a sample from an area of peat [SJ 7182 9650], which probably reflects enhanced adsorption of air transported Pb by organic matter. High Pb, Cd, Cu, Ni, Zn, Fe and Mn (Manganese) concentrations characterise peat samples taken outside the Wigan area.

Surface water geochemical data

The number of samples in which the CEC MAC levels are exceeded are indicated in Table 13. The CEC MAC for Aluminium (Al) and Nickel is exceeded at 2–3 sites; Fe, Mn and sulphate MAC's are exceeded at 6–15 sites. Sulphate, Mn, Fe, and Ni are very high compared with water concentrations in rural areas of North Wales, possibly indicating a high background for these elements in surface waters associated with the Coal Measures. Colliery spoil produces high sulphate, Mn, Fe, (+/- Al, Ni, Cu and Zn) concentrations in surface waters; pH of surface waters in colliery spoil areas is slightly lower (6–7) than in rest of the Wigan area (pH 7–8).

Coal mine drainage waters typically contain high concentrations of iron, sulphate and sometimes also cadmium, copper and zinc. Further details on the nature of waters from coal mines and mine spoil can be obtained from the NRA, Water Quality Series, Report No. 14: Abandoned mines and the water environment. Although iron (Fe) is normally the major contaminant from coal mines, only one water sample from the Wigan area exceeds the UK standard for iron of 1 mg/l, set in 1989 (Anon, 1994e).

One very high Molybdenum (Mo) value in water (1338 ppb) is associated with low pH stream water derived from mine spoil. High Mo was also detected in the stream sediment at this site. This may reflect high concentrations of Mo in black shales within the Coal Measures strata. Low pH and high cation concentrations and low sulphate levels are associated with peat and the Millstone Grit. Water monitoring data for List 1 and List 2 trace metals can be obtained from the National Rivers Authority.

CONCLUSIONS

The geochemical data indicate extensive contamination of stream sediments, soils and surface waters in the Wigan area, although the level of contamination is not particularly high. Much more detailed sampling is required to identify the concentrations of potentially harmful elements relating to specific areas of present and past industrial use, made ground, backfilled areas and mining (Maps 6 and 9). Sampling and analysis of surface soils collected at a density of 4 samples per km^2 has been used for urban geochemical investigations in the Wolverhampton area (BGS, unpublished data).

Table 12 Statistical summary of minus 150 μm soil data from Wigan area. All values in ppm.

Element	Northern Britain Range	50%	90%	Wigan area Range	50%	90%	'Contamination Level' ①	WMB n>'Contamination Level' ②
Pb	15–8000	55	98	17–7643	55.5	182	500	1
Cd	0–13.1	0	0.8	0–5.7	0.1	1.1	3	0
Zn	0–3128	123	237	0–3471	90.5	182	300	4
Cu	4–1500	27	42	7–1377	37.5	118.9	130	4
Ni	7–357	41	59	19–269	44	67	70	4
Cr	21–706	108	145	0–348	127	348	600	0

① ICRCL threshold trigger concentration.

② Number of samples in Wigan MBC exceeding ①.

Table 13 Statistical summary of stream water data from Wigan area. All values in ppm.

Element	Northern Britain and Wales Range	50%	90%	Wigan area Range	50%	90%	'Contamination Level' ①	WMB n>'Contamination Level' ②
Pb	0–?	<d.l.	89	<d.l.	—	—	50	0
Cd	0–?	<d.l.	5.6	0–4.1	<d.l.	<d.l.	5	0
Zn	0–?	4.8	20	<d.l.	—	—	100*	0
Cu	0–?	<d.l.	7	0.6–85	11.3	45.8	100*	0
Ni	0–?	<d.l.	16	0–107.6	4.8	26.6	50	3
Al	0–	40	124	9.9–613	40.9	195.6	200	2
Fe	0–	82	392	0–11 991	156	863	200	13
Mn	0–	25.4	226.2	0–9118	123	1568	50	15
SO4	0–?	11.9	30.7	0–410	74	432	250	6
Cl	0–	18.6	41.8	6–99	33.5	58.2	200	0

① CEC MAC for drinking water (except Cu and Zn which are CEC guide values.

② Number of samples in Wigan MBC exceeding ①.

15 Engineering geology

CLASSIFICATION AND MATERIAL CHARACTERISTICS

The geological materials in the Wigan Metropolitan Area may be divided on the basis of their engineering geological behaviour with regard to land use and construction (Table 14, Map 8). The primary division is into 'engineering rocks' and 'engineering soils'. In broad terms engineering soils may be excavated by digging and comprise the geological 'Superficial' formations and some weathered, soft bedrock formations. Engineering rocks comprise the hard and unweathered 'Bedrock' formations and generally require a more vigorous means of excavation than digging.

The primary divisions are subdivided on lithological grounds into 'sandstone' and 'mudstone' rocks while the soils are divided into the equivalent 'non-cohesive' (sand) and 'cohesive' (clay) units. No mappable units of entirely cohesive soil are present in the area and a category of 'mixed cohesive/noncohesive' has been used to indicate units which comprise combinations of discrete bodies of cohesive and noncohesive material. 'Organic' soil is present in significant, mappable but geographically restricted amounts, in the form of peat, mainly in the moss lands in

Table 14 Geological materials classified on the basis of their engineering geological behaviour with regard to land use and construction.

ENGINEERING UNIT	GEOLOGY UNIT	CHARACTERISTICS
ROCKS		
'Strong' Sandstone	Coal Measures Sandstone	Moderately strong to strong, fine to coarse grained sandstone with mudstone and siltstone interbeds; moderately to well jointed, thinly to thickly bedded
'Weak' Sandstone	Collyhurst and Sherwood Sandstones Pebble Beds	Moderately weak to moderately strong reddish brown, generally poorly cemented sandstone. Sometimes pebbly. Weathers to medium dense to very dense sand
'Strong' Mudstone	Coal Measures Mudstone	Weak to moderately strong, grey, mudstones and siltstones. Some thin sandstones are present. Weathers to very soft to very stiff, silty clay and shaly clay of low to high plasticity with sandstone pieces
'Weak' Mudstone	Manchester Marl	Reddish brown to purple, stiff to hard mudstone with grey/green zones and thin sandstones. Weathers to a soft to stiff clay
SOILS		
Mixed Cohesive/Non-Cohesive		
Stiff/Dense	Till (Boulder Clay)	Mainly firm to very stiff, becoming hard with depth, brown, fissured, gravelly, silty, sandy, clay. May contain lenses and layers of silt, sand or gravel the relative thickness of the units varies across the area
Soft/Loose	Laminated Clay Alluvium	Laminated clay mainly soft clay with sandy silty layers. Alluvium very soft to stiff, brown and grey, silty sandy clay or loose to medium dense, brown or grey, clayey sand both with clayey, silty, peaty lenses and layers
Non-Cohesive		
Fine	Shirdley Hill Sand	Generally thin, windblown, very loose to loose, dark brown, fine to medium sand or sand and gravel with peat lenses and layers
Coarse	Glacial Sand/Gravel Outwash Gravel	Loose to dense, fine to coarse, brown, sand and gravel. May be silty or clayey and contain lenses of silt and clay
Organic	Peat	Up to 3 m thickness of fibrous peat over amorphous peat in the 'moss' areas. Surface layers modified by cultivation and the addition of various soil improvers
Highly Variable Mixed	Made Ground Fill	Very variable in composition colliery spoil, ash, rubble, stones, gravel, sand, clay etc. Geotechnical properties unpredictable

the south east of the area. A fourth category of 'highly variable mixed' material has been designated to describe the extensive areas of made ground and fill which cover much of the area.

The secondary divisions are further divided on the basis of strength in the case of the sandstones, mudstones and mixed cohesive/noncohesive materials and on grain size for the noncohesive soils. The engineering geological divisions which result may comprise more than one geological unit but represent a class of material which will show a similar behaviour in an engineering situation. The accuracy of the division is constrained by the fact that they are based on mapping which was carried out for geological, not engineering geological or geotechnical, purposes.

The engineering geological map is further constrained by a lack of subsurface data, since the design and stability of a structure placed on the surface will be influenced by the properties of the ground for some depth below it, the depth depending on the load imposed by the structure and the area over which it is imposed. Thus, where a geological formation such as till is present, it may contain lenses of material with strongly contrasting properties to those exposed at the surface. In such materials extensive subsurface investigation is necessary to determine the distribution of materials below the ground surface and their geotechnical properties.

An indication of the conditions below the upper geological deposit has been given on the map using a variation of the 'stripe' method of Pasek and Rybar (1961). Where bedrock formations outcrop at the surface or where superficial deposits are greater than 5 m thick the engineering geological unit is shown as a solid block of colour. Where the superficial material is less than 5 m thick the colour of the superficial engineering geological unit is shown in stripes, interspersed with stripes of the colour of the underlying bedrock colour. Thus, an indication is given of the surface and subsurface bedrock material.

However, there is insufficient detail available to indicate where there are other superficial materials present between that exposed at the surface and the bedrock interface. Other superficial materials may be anticipated below thin alluvium or within till, where sand bodies are known to be present within the predominantly clay-rich material.

ENGINEERING ROCKS

The engineering rocks of the Wigan area are covered generally by thick superficial deposits. Therefore, they are infrequently encountered in the course of construction and development; consequently few geotechnical data are available on which to base their predicted engineering behaviour. The engineering geological descriptions of the bedrock formations are based on data which were available from site investigations in the area, published data for the same or similar formations in other areas and the geotechnical data bases created for other coal mining areas which have been the subject of other applied geological studies by the British Geological Survey for the Department of the Environment.

'STRONG' SANDSTONE

The Coal Measures sandstone, when fresh, is generally moderately strong to very strong, fine to coarse grained with mudstone and siltstone interbeds. It is moderately to well jointed and thinly to thickly bedded. No strength values were found for the Wigan area but data from other areas indicate that most sandstones will fall in the range 12.5 to 200 MPa with low values being given by weathered material and the high values only being achieved by exceptionally well-cemented examples. Discontinuities and bedding may be expected to be, generally, of medium spacing but in the major sandstones such as the Ravenhead Rock, Cannel Rock and Trencherbone Rock the discontinuities may be widely spaced and the bedding may be thick.

The 'strong' sandstones may be expected to offer good foundation conditions and bearing capacity except where shallow undermining is present or where faults may be reactivated or act as pathways for methane or radon movement. Generally, excavations in the sandstones can be achieved by ripping but in the thicker, stronger units blasting may be necessary. The stability of excavated faces will depend on the frequency, tightness, and roughness of discontinuities and their orientation relative to the cut face. The excavated material should be suitable as rock fill.

'WEAK' SANDSTONE

The Sherwood Sandstone is, generally, a moderately weak to moderately strong, fine to medium grained, red, brown or yellow, sandstone, which frequently weathers, at outcrop, to a dense to very dense sand. In Lancashire it appears to be more porous (10%–30%) than in Yorkshire (0%–20%) (Crook et al., 1971). In the Nottingham area the Nottingham Castle Formation of the Sherwood Sandstone, with a moisture content range of 2%–26% gave strength values in the range 1–22 MPa (Walsby et al., 1993). The strength of the Sherwood Sandstone in the Wigan area may be expected to have a comparable range.

The Pebble Beds are similar to the Sherwood Sandstone but contain well rounded pebbles of quartz, randomly scattered or in crude laminations. It is expected that they will exhibit similar geotechnical properties to the main Sherwood Sandstone facies.

No geotechnical data were found for the Collyhurst Sandstone but it is expected to be a weak or moderately weak, red, medium to fine grained, well sorted, sandstone. In some parts, where cementation is absent or has been removed by weathering or other processes, it becomes a dense to very dense sand.

The 'weak' sandstones are expected to offer reasonable foundation conditions if care is taken to remove unsuitable, weathered material. Faulting or fissuring induced by past undermining may be present which may cause damage to foundations if they are reactivated, or if loose superficial material flows into the void causing loss of support to the foundation. Fissures, faults and the generally permeable nature of the material can give an enhanced risk from the accumulation of the potentially hazardous gases radon, methane and carbon dioxide. Suitable foundation design and the ventilation of basements and under floor spaces may be used to minimise such hazards. The possibility of frost heave should be considered where fine grained material is present below shallow foundations such as concrete aprons and paths.

Excavation may be expected to be achieved by digging in the weaker and weathered material, with the possibility of ripping being necessary in the stronger, fresher material. The stability of the sides of an excavation may be impaired, in weathered or un-cemented material, if the water table is penetrated and running sand conditions are generated. In some cases provision for de-watering, close boarding, sheet piling or water cut-offs may need to be considered. In permanent, excavated slopes similar precautions against running sand conditions may need to be made and provision for controlling surface water run-off should be considered. Excavated fresh material should be suitable as fill.

'STRONG' MUDSTONE

The 'Strong' mudstone unit comprises the Namurian and the Coal Measures (Westphalian A, B and C) strata and includes minor siltstones and sandstones. The mudstones are generally very weak to weak and weather to stiff to very stiff, low to high plasticity, inorganic clays, silty clays and silty, sandy clays with moisture contents in the general range 12%–22%. Near to the surface the material may become soft or very soft in wet areas. Coal Measures data from other areas indicate Coal Measures clays to be of low compressibility with a medium rate of consolidation (Forster, 1991; 1992)

The Coal Measures mudstones may offer reasonably good foundation conditions if soft material is removed and allowance is made for long term consolidation. However, the possibility that the ground has been undermined should be regarded as quite high in the Wigan area and the appropriate sources of mining records should be consulted. In addition site investigations should be designed with the intention of detecting workings beneath the site because former workings may not have been recorded or their records lost. If old workings are present consideration will need to be given to dealing with them by appropriate foundation design, grouting, digging out followed by controlled backfilling or the inclusion of a basement in the development (Chapter 11).

Excavation may be expected to be by digging in the weaker and weathered material, aided by pneumatic tools or possibly by ripping in the harder mudstone or sandstone beds, if present. Excavated material should be suitable for engineering fill if the moisture content is low and placement is in dry conditions. The stability of excavated slopes will depend on the degree of weathering of the slope forming materials and the groundwater regime. Cuttings and embankments at slopes of between 1:2 and 1:4 may be expected to be stable in the long term depending on lithology and local conditions.

'WEAK' MUDSTONE

Few geotechnical data were available for the Manchester Marl which is a dark red or chocolate brown mudstone with minor interbedded sandstones and limestones. The geotechnical data indicate it to be stiff to hard, reddish brown mudstone with bands of sandstone becoming soft or very soft near to the surface. It is expected to give reasonable foundation conditions, to be diggable but may be unsuitable for engineering fill. However, in the absence of geotechnical information, or of data from other areas, no confident predictions of behaviour can be made.

ENGINEERING SOILS

The engineering soils in the Wigan area comprise superficial geological deposits and weathered, weaker, bedrock materials. The Wigan Metropolitan Borough is mainly covered by superficial deposits and therefore civil engineering activities in the Wigan area will generally encounter engineering soils rather than engineering rocks, except in the relatively small areas of exposed bedrock or bedrock where superficial cover is thin (Map 3). No bodies of completely cohesive soil have been mapped geologically. Although the till (boulder clay) which covers much of the area is composed mainly of clay-rich cohesive material, it includes, within it, significant bodies of non-cohesive sand and gravel which could not be delineated without extensive, subsurface data.

Mixed cohesive and non-cohesive soils

The 'mixed-cohesive and non-cohesive' soils of the Wigan area may be divided into two groups based on their relative density/consistency.

STIFF/DENSE

This sub-unit is represented by the till (boulder clay) which covers much of the area. The till comprises mainly stiff to very stiff, brown, overconsolidated silty, sandy and stony clays but included within it there are large and small bodies of medium dense to dense glacial sand and gravel. In places the till contains laminated clays, silts and sands. The frequently irregular and lenticular nature of the laminated material, glacial sand and gravel bodies within the clayey till and the absence of correlatable characteristics make it very difficult to delineate the areal extent of such bodies within the till, or to identify different till units within the mapped body. Formerly, the till was divided into an upper clay, often laminated at the top, and a lower, less commonly laminated, unit separated by a sand/gravel unit (Jones et al., 1938). However, it is now regarded as a single till overlying very dense sand and gravel and containing some areas of multiple succession (Chapter 8).

The geotechnical properties of till will vary according to its composition and its geological history. This may include consolidation, overconsolidation, unloading, periglacial processes and weathering. In the absence of a detailed geotechnical database it is not possible to assign geotechnical properties to particular sub units within the till and comment is restricted to the lithological material types which comprise the till, rather than geographically-defined sub-units.

Till may be soft in the near-surface zone or may be desiccated and stiff at the surface becoming, initially, softer below the desiccated zone and then stiffer with increasing depth. The till is typically of low to high plasticity which is a reflection of its range in composition from sandy/silty clay to clay. When plotted on a Casagrande plot (Casagrande, 1948) the plasticity values tend to fall on the T-line rather than the A-line, thus implying that it is an undisturbed lodgement till (Boulton and Paul, 1976). Bulk density is usually in the range 1.90–2.25 Mg/m^3. In overconsolidated, fresh till, consolidation may be expected to be low but if stress relief and softening has taken place consolidation may be higher. Where it is laminated, the more sandy and silty layers will increase permeability, allowing both softening or consolidation of the clay-rich layers to proceed more rapidly.

The fresh, overconsolidated, stiff to hard till may offer good foundation conditions but if it is weathered and softened its bearing capacity will be lowered. Site investigation should ensure that the material below foundation level is free of soft ground and that water-bearing sand or gravel layers are not present below the foundations which might cause softening or heave under artesian conditions. The possibility of old mine workings below the till should be considered where the till cover over bedrock is thin.

Excavations in till should be achievable using digging machinery with the prospect of hard digging in areas of harder, overconsolidated material. If water-bearing sands are encountered, running conditions may require control and basal heave due to water-bearing sands under artesian pressure may be a problem. The use of excavated material as engineering fill may be possible but because of the variation in material within the till, its suitability will need to be determined on a site specific basis. The stability of artificial cut slopes and natural slopes will be dependant on the local lithology and groundwater conditions but few instances of actual, or suspected instability, were found during the project. The till may soften rapidly when water is encountered and movement of site traffic may be difficult in wet weather if the ground becomes heavily churned.

SOFT/LOOSE

The materials which comprise the 'soft/loose mixed' deposits are alluvium and laminated clay. The alluvium is generally composed of normally consolidated, very soft to firm, sometimes stiff, brown and/or grey, low density (1.80–2.10 Mg/m^3), high moisture content (15–35%), silty, sandy clay of low to intermediate plasticity and, loose to medium density, dark grey and/or brown, silty, clayey sand and gravel. The alluvium may also contain lenses or layers of dark, organic clay or peat which will have lower densities and higher moisture contents. The cohesive and non-cohesive material may occur as layers or as lenses of one in a larger unit of the other. In the near-surface zone the clayey alluvium may become desiccated and assume a stronger consistency than the underlying material.

The laminated clays are of glacial lake origin and are generally soft to firm. In the near-surface zone they readily soften when exposed to wet conditions and may become very soft. They are often slightly more plastic than the alluvial clays since deposition in lacustrine environments may retain more clay material than deposition in alluvial environments.

The 'soft/loose mixed' engineering geological unit may not offer good foundation conditions due to its low strength giving a generally low bearing capacity. The material may suffer high settlement at a rate dependant on the permeability of the material concerned. Light structures with suitable foundations to spread their load may be designed but it is possible that the ground's bearing capacity will vary with local variation in lithology and this may cause unacceptable, uneven settlement.

Excavations in this unit may be expected to be achieved easily with digging machinery but the weakness of the material may cause instability of the cut faces. Instability may be aggravated if water-bearing sands are met which may give rise to flooding or running sand conditions. The excavated material is unlikely to be suitable for use as engineering fill because it may be too variable and/or too wet. The presence of a desiccated crust may give a false impression of ground conditions because softer material may be present below the crust. If the crust is disrupted by site traffic then trafficability may become poor.

Non-cohesive material

The 'non-cohesive' engineering geological unit is subdivided on the basis of grain size into 'fine' and 'coarse' sub-units.

'FINE'

This unit comprises the Shirdley Hill Sand which is a thin deposit of wind blown sand covering parts of the till outcrop in the south-west of the area. It was formerly worked as a raw material for glass manufacture and areas shown on the map may have been largely removed (Chapter 10). They are very loose to loose, fine to medium grained, white, grey or brown, sand which may be peaty or contain peat layers.

The Shirdley Hill Sand would be unlikely to offer good foundation conditions due to its loose nature and the presence of peat or peaty layers within it. Settlement is likely to be high and rapid, but may be uneven depending on the disposition of peaty material, the thickness of the unit and the topography of the underlying material. Buried hollows, or stream channels, are particularly prone to high and uneven settlement. If shallow foundations are placed on the sand, such as concrete paths or hard standing, consideration should be given to the possibility of frost heave.

In many cases the Shirdley Hill Sand may be thin enough to be removed during the early stages of construction. Excavation may be easily accomplished by digging but cut face stability may be poor and require immediate support. The excavated material may be suitable for granular fill if it is carefully selected to exclude unsuitable organic material.

'COARSE'

The 'coarse non-cohesive' unit comprises glacial outwash and other sand and gravel. The outcrops of these materials are shown on Map 8 but they are also present as extensive sub-surface deposits within and below the till. At outcrop, and in the near-surface zone, this unit will be loose to dense but at depth, within and below the till, it may be dense or very dense. The sands and gravels may be silty or clayey and may contain lenses of silt, silty clay or clay.

The 'coarse non-cohesive' material offers good founding conditions except for the possibility of included lenticular bodies of material of contrasting properties or where it is thin over an uneven interface with other materials of contrasting geotechnical properties. In these cases unacceptable uneven settlement may occur. Excavations should be possible by digging but problems from running sand and cut face instability may occur when excavation is in loose material or is below the water table. The excavated material should be suitable for granular fill if care is taken to exclude any unsuitable silty or clayey material.

Organic

Organic soils and peats occur as small isolated patches in wet hollows and streams in many parts of the Wigan area, and are particularly associated with the Shirdley Hill Sand. Large areas of geologically mappable peat are found mainly in the Moss Land areas such as Chat Moss and Ince Moss. Organic soils and peats have a wide range in their geotechnical properties but may all be regarded as problem soils for the purpose of construction. They are typically of low density, high moisture content and of low strength. All peats suffer very high consolidation on loading. The fibrous peats consolidate rapidly but the more clay-rich, amorphous peaty soils will be much slower. The nature of peat bodies is such that they are frequently irregular or contain bodies of other materials of very different geotechnical properties; thus differential settlement may be a major problem. Consolidation also may take place as a result of drainage lowering the water table.

Organic soils offer bad foundation conditions due to low and uneven bearing capacity giving excessive, rapid and often uneven settlement. The groundwater conditions in organic soils and peats may be highly acidic and cause damage to buried services and concrete. Excavation is easily accomplished by digging but conditions will vary according to the nature of the material. Very wet, amorphous, peaty soils may suffer poor face stability and in extreme cases flow into the excavation but the more fibrous peats may stand well without support. The excavated material will be unsuitable as fill but in some cases may be suitable for use as agricultural or horticultural peat.

Highly variable mixed

This engineering unit is composed of the artificial deposits in the area which comprise made ground and fill. The materials range from mixed Coal Measures strata infilling opencast coal sites to domestic and industrial waste tips. The geotechnical properties of these materials will be very different but since they are the result of human activity they all have the potential for containing unexpected, unpredictable ground conditions (Anon, 1983a).

Made ground which was created during modern, engineering operations such as earthworks and embankments for roads or opencast mining is formed under controlled conditions (Anon, 1981c) and care is taken to ensure its stability and suitability for its eventual designed end use such as a road foundation, return to agriculture or industrial development. Made ground generated by engineering work in the distant past, when land was less valued and environmental issues not so highly regarded, may have had less regard paid to its future use and the ground conditions which resulted may not be to current best practice. However, in either case the ground conditions may be reasonably uniform within a deposit and be reasonably predictable once the nature of the material has been identified. It may be expected that, if tipping and compaction has been carried out with care, then bearing capacity may be reasonable and uniform.

Made ground and fill generated by the disposal of domestic and industrial waste in recognised tips or elsewhere are, potentially, a much greater problem to construction and land use. The material present may include a very wide range of inorganic, organic, inert, reactive, harmless and toxic substances. In the worst case these materials may have been tipped without regard to compaction, containment or their potential to interact with each other and the environment, and no record may have been made of what has been deposited. It is difficult to predict the engineering properties of such made ground since it will be highly variable across its area and with depth. Geotechnical properties will also vary with time as material decays and the nature of old tips cannot, be used necessarily as a guide to the future behaviour of recent tips because the nature of domestic waste has changed through recent history (Chapter 12).

Made ground containing domestic waste generally offers poor ground conditions with low bearing capacity, high and uneven settlement and the possible leakage of methane and/or leachate which may reach hazardous levels. The accumulation of methane in closed spaces in buildings, sub-floor spaces or basements may reach explosive concentrations (5–15% in air). Made ground containing industrial waste may contain toxic and reactive material which may increase the hazards associated with domestic waste such that the land may need remedial treatment before further use or to avoid pollution affecting adjacent areas. Modern waste disposal practices will result in ground conditions much better than in the past and the use of suitable foundations, sealing and/or ventilation of basements will enable sites to be used for many end uses (Chapter 13).

When a made ground site is involved in a construction project or is being considered for redevelopment, it is essential that the nature of the materials present in the ground are identified, their disposition in the ground mapped and their geotechnical properties determined. Other properties such as chemical and biological ones also may need to be examined depending on the nature of the material found. The investigation of such ground is a specialist task and must be carried out in compliance with best current practices (Anon, 1981b; Anon, 1983b; Anon, 1993) and with regard to the safety of the site personnel and the public.

Prior to a ground investigation a thorough desk study should be carried out to identify the possible nature of the materials present and any hazards that they might contain. The Institution of Civil Engineers, Site Investigation Steering Group Report on 'Site investigation in construction' is an important guide to current practices (Anon, 1993). Part four 'Guidelines for the safe investigation by drilling of landfills and contaminated land' is particularly relevant.

LANDSLIDES

The National Landslide Survey carried out by Geomorphological Services on behalf of the Department of the Environment (Anon, 1987b) did not identify any specific landslides in the Wigan area. Two areas described as 'possible areas with extensive ancient landsliding' were indicated, at Hindley Green and between Shevington and Gathurst. Examination of aerial photographs of these areas and a brief, field inspection did not indicate these areas to contain obvious landslides. However, it is to be expected that during the periglacial conditions at the end of the last Ice Age extensive areas of active, shallow landsliding and solifluction would have been present on low angle slopes throughout much of Great Britain. Since then, these areas have become stable, degraded and difficult to recognise from surface features. The shear surfaces generated by these shallow movements remain below the ground surface and are capable of reactivation if the slope becomes saturated, or is undercut by excavation at its foot. Therefore, when slopes are developed or altered the consequences to slope stability of the slope and its surrounding area should always be assessed.

Two recently active landslides were found on the east side of the valley of the River Douglas at Whelley [SD 5881 0648, SD 5881 0643]. These shallow rotational failures took place on the steep valley side of the Douglas valley after a period of wet weather but interpretation of the mechanism and cause of the instability was complicated by recent construction, made ground and shallow undermining of the area in the Ince Furnace Mine coal seam. Examination of the slope to the north of the area showed old, small slides beside the footpath. This area, and much of the Wigan Metropolitan Area, is an urban area with a long history of occupation and use. Therefore, it may be difficult to identify old landslide areas because they have been buried or smoothed over. Also, some activities such as mining may mimic the hummocky slope topography often associated with landslide activity.

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GLOSSARY

AEOLIAN DEPOSITS Sediments deposited after transport by wind.

ANAEROBIC Conditions in which oxygen is absent.

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

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

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

BEDROCK Unweathered rock beneath a cover of soil or superficial deposits.

BOULDER CLAY An obsolete term for till.

BROWN SOILS Deep or moderately deep, dominantly brown or reddish soils with no prominent mottling or greyish layers above 400 mm depth.

CANNEL apropelic coal formed mainly of lycopod spores and algae, probably deposited in anaerobic lake conditions (unlike coal seams which represent the compacted and lithified remnants of swamp peat). Cannel is black, fine grained and tough with a dull greasy lustre and a conchoidal fracture. It has a high percentage of volatiles and burns with a smoky, luminous flame, somewhat like a candle, giving the coal it's name.

CARBONIFEROUS Period of geological time ranging from about 345 to 280 million years before the present.

CLEAT Cleavage in coal.

CLEAVAGE Preferred plane of parting in a rock or mineral.

COAL Coal is a carbon-rich deposit formed from the remains of fossil plants deposited initially as peat, but burial and increase in temperatures at depth bring 'coalification' resulting in the production of coals of different rank, each rank marking a reduction in the percentage of volatiles and moisture, and an increase in the percentage of carbon. Coals in the Wigan area are of bituminous rank and range in thickness from coal traces to about 3m.

CROSS BEDDING A series of inclined bedding planes having some relation to the direction of current flow.

CYCLOTHEM A sequence of strata repeated as a result of cyclical changes in sea level.

DEVENSIAN A geological succession dating from approximately 0.12–0.10 Ma (part of the Pleistocene epoch) and representing a period of glaciation which partly covered England.

DIP The inclination of a planar surface from horizontal. Usually applied to bedding planes. The correct term for this for fault planes is "hade".

DRIFT Archaic synonym for superficial geological deposits.

FAULTING Faulting is the displacement of blocks of strata relative to each other along planar fractures. Movement may take place in several ways, depending on the direction of the compressive or extensional forces acting on the rock mass forming normal, reverse or strike slip faults.

FAULTS Faults are planes in the rock mass on which adjacent blocks of rock have moved relative to each other. They may be discrete single planes but commonly consist of zones, perhaps up to several tens of metres wide, containing several fractures which have each accommodated some of the total movement. The portrayal of such faults as a single line on the geological map is therefore a generalization.

FOLDING Folding is the flexuring and bending of originally planar rock layers into curved surfaces.

FORMATION The basic unit of subdivision of geological strata, and comprises strata with common, distinctive, mappable geological characteristics.

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

GREY SOILS Slowly permeable, seasonally waterlogged, prominently mottled soils.

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

GROUP A stratigraphical unit usually comprising one or more formations with similar or linking characteristics.

INTERGLACIAL Ice ages are often divisible into periods of maximum advance and periods of ice retreat. A period of retreat is referred to as an interglacial.

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

LACUSTRINE Pertaining to lakes.

LAMINATED Description of very thin bedding less than 10 mm thick.

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

LEAVES Coal seams vary laterally in thickness and some seams are split by interdigitation of other sediment to give two related layers or leaves.

MARINE BAND These are deposits of black, fossiliferous, marine shales which formed during periods of high sea-level. They are useful as marker horizons, as individual marine bands have a distinctive fossil content and can be traced over wide areas (commonly 500 km of lateral continuity). Identification of a marine band enables the relative position in a geological sequence to be established.

METHANE A colourless, odourless, inflammable gas which forms an explosive mixture with air.

MEMBER Subdivisions of a formation each characterised by relatively few and distinctive rock types and associations (for example, sandstones, marls, coal seams).

MINE The term used for coal seams in the Lancashire coalfield (e.g. Arley Mine). There are approximately 40 named coal seams in the district, at least 36 of which have been mined. Coal seam nomenclature suffers considerably from different coal seams being called the same name (e.g. Bulldog) and, conversely, from the same coal seam being called different names (e.g. Ince Seven Foot and Brassey). The seam names which appear on the geological map and in this report are based on the correlation of Ridgeway (1983) which was adopted as the standard classification by British Coal.

MUDSTONE The dominant lithology in the Coal Measures. It ranges in colour from light grey to dark grey. Although fossiliferous immediately above a coal seam, mudstones are generally devoid of organic remains elsewhere. The mudstones usually become increasingly silty upwards and grade into siltstones or pass by intercalation and interlamination with sandy beds into fine grain sandstone. A multitude of old terms have been used to describe mudstones including: bass, bat, bind, flue, leys, metal and soapstone while lin, linsay, linstey or lin and wool were use for interlaminated shale and sandstone.

NORMAL FAULT A fault in which the movement of one face of the rupture moves predominately down the fault plane relative to the other face.

OROGENY An episode of uplifting of the earth's crust and development of mountains involving rock deformation over a long period of time.

OUTCROP The area over which a particular rock unit occurs at the surface.

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

PERMO-TRIASSIC Strata belonging to the Permian and Triassic systems but undifferentiated.

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

PODZOLIC SOILS Soils with a black, dark brown or ochreous subsoil layer enriched in iron and humus

ROCKHEAD The upper surface of bedrock at surface or below a cover of superficial deposits

SANDSTONE Sandstones are medium grained clastic rock, usually pale grey or cream at depth, but near the surface they weather to rusty-brown or, less commonly, white. They are generally well-cemented and strong with quartz being the dominant component. They commonly form widespread sheets, less than 5m in thickness, or elongate channel deposits. 'Washouts' occur where such channel sandstones cut down into, and remove, underlying coal seams. Channel sandstones are coarsest at the base, containing up to pebble sized clasts, and sometimes 'rip-up' clasts of the soft underlying sediments or coal. The old mining terms burr, rag, rock, rockbind and wool are synonymous with sand- and siltstones.

SEATEARTH Seatearths are fossil soil horizons developed under sub-aerial conditions. Seatearths are characterised by the presence of rootlets and the absence, or extreme disruption, of bedding. Although every coal seam will have an associated seatearth, not every seatearth will be accompanied by a coal seam, and there is no correlation between the thickness or character of a seatearth and that of the overlying coal. Commonly, seatearths developed in sandstones are known as gannisters while those developed in mudstones are termed fireclays. Other terms include: Bally seating, clod, clump, clunch, floor, seat, underclay or warrant.

SHALE A form of mudstone with a well-developed bedding plane parting.

SIDERITIC IRONSTONE An iron-rich rock, developed either as nodules, generally flattened parallel to bedding, or as layers. In the metre or so above coal seams it typically forms laterally continuous beds up to about 100 mm, or so, in thickness. Ferruginous concretions are common in seatearths. The terms balls (iron balls or raddle balls), blackband and raddle are generally synonymous with ironstone.

SILTSTONE A sedimentary rock intermediate in grain size between sandstone and mudstone.

SUPERFICIAL DEPOSITS A general term for usually unlithified deposits of Quaternary age overlying bedrock; formerly called drift.

TILL An unsorted mixture which may contain any combination of clay, sand, silt, gravel, cobbles and boulders deposited by glacial action without subsequent reworking by meltwater.

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

WASHOUT A coal mining term used to describe a channel cut into strata (usually coal) subsequently filled by sediment such as sand or silt.

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APPENDIX I

The computer database structure and user's guide

THE COMPUTER DATABASE

The database records exist in the form of an index, a guide to what data is available, rather than a database of raw geological data. The user is presented with a list of records that are available within a chosen area or on a given subject. Information is always given concerning the holder of that data. Taken as a whole, the product is a stand-alone system that provides a directory of geological information covering specific topics and geographical areas within the Wigan MBC. The information can be viewed as one complete record at a time. Users are guided by simple menus as to which records they wish to view — whether by subject or area and then by a specific search for an item, if required.

Special screen formats have been designed to display the records for viewing, searching or editing. There is a facility to print out any records as required as well as a facility for backing up the database for security purposes.

Simple menus restrict the need for any detailed computer knowledge. The only input that is required is a choice of option from the appropriate menu; the normal 'escape' procedures have been withheld, leaving the user only the menu choices presented on the screen, which always provide a path back to the preceding menu or the initial main screen menu.

This appendix provides a brief guide to the program and its operation. Selected examples of the screen formats and user choices are given in this Appendix, a detailed user guide and installation instructions accompany the disk containing the Wigan database. A more detailed analysis of the program is provided in British Geological Survey Technical Report, WA/93/30.

Upon entering the program the following initial screen is displayed:

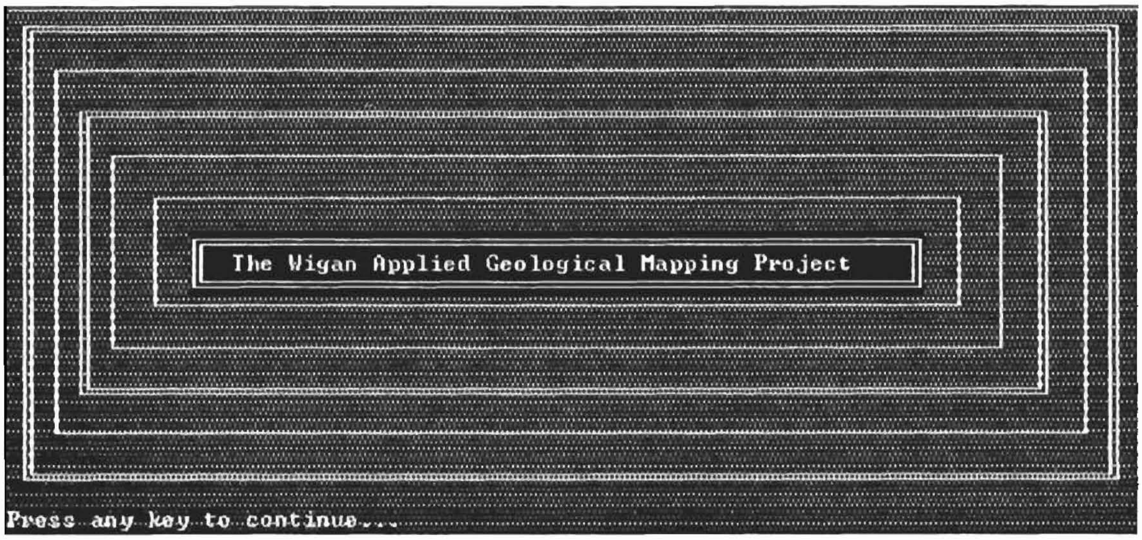

Figure A1 Initial screen.

Pressing any key allows entry into the system main screen enabling the user to select data according to subject or area and to append data.

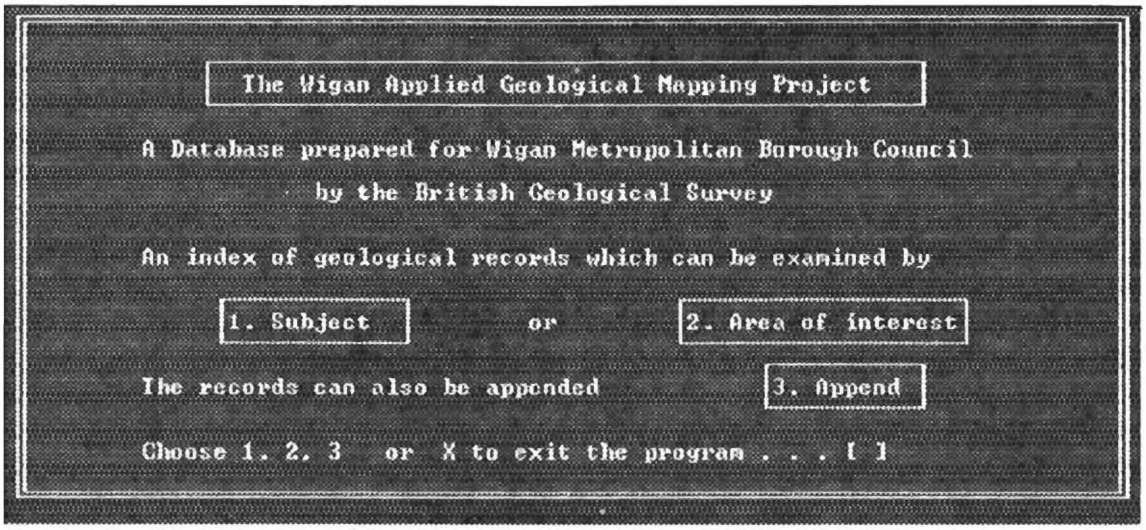

Figure A2 Main screen.

Upon entering the program the following initial screen is displayed:

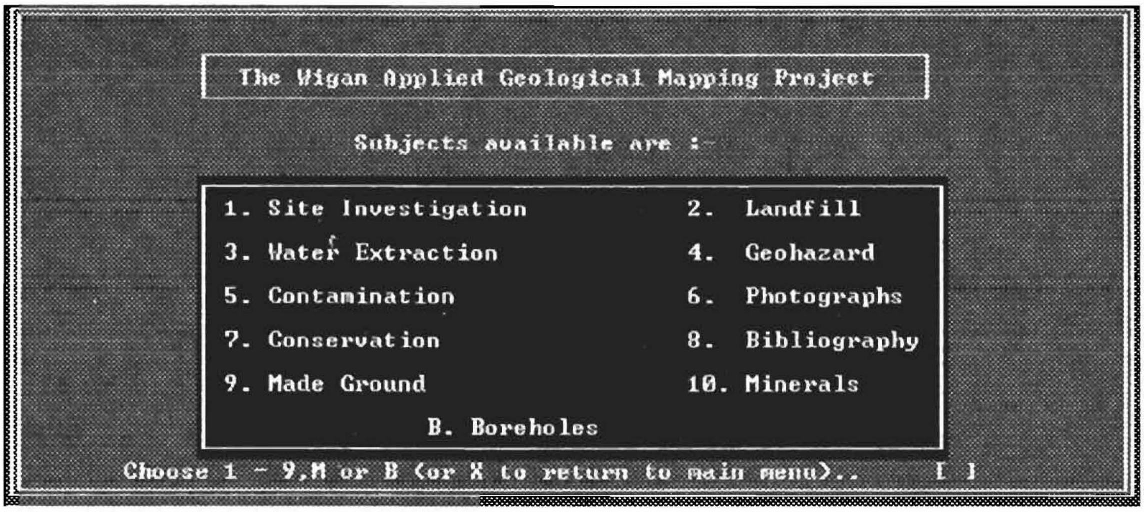

Figure A3 Subject screen.

This gives 11 subjects within the database to examine plus the option of returning to the main menu. Once a choice has been made the program will sift the database to find records that match the user's choice. Following the choice of **B. Boreholes** the following screen will be encountered (Figure A4); here the user can choose whether to view all of the available records or to set up a search for particular data. If there are no records, then no options will be available and the user is only able to return to the main screen (Figure A2).

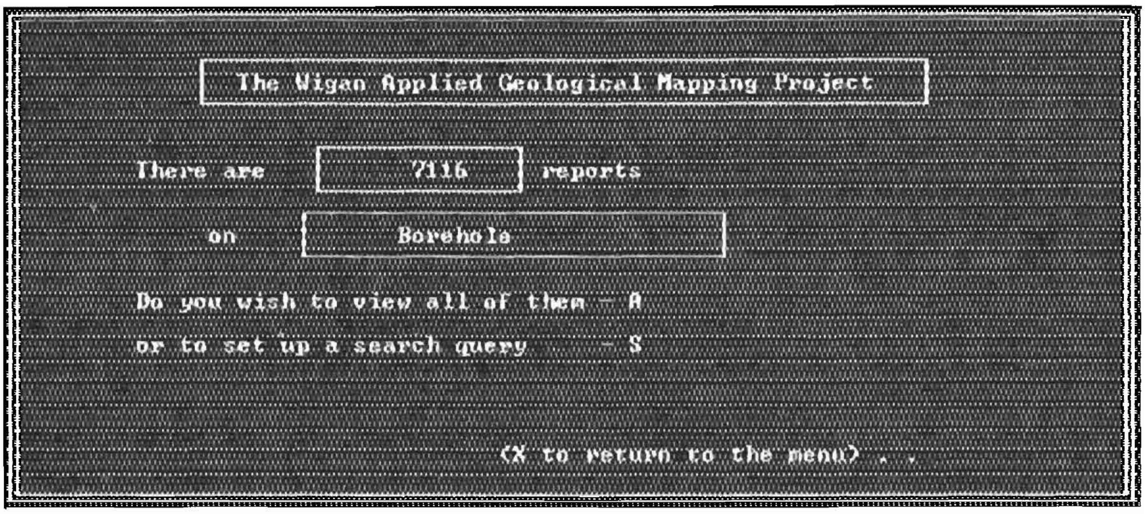

Figure A4 Result of subject search.

Choosing A (for all) displays the following screen:

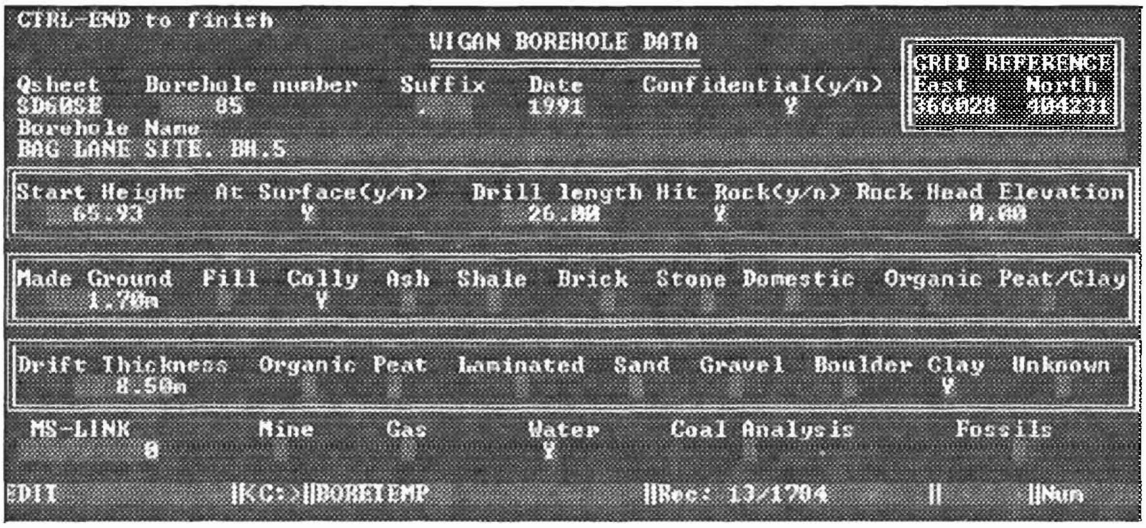

Figure A5 Borehole display screen.

This is the format for the individual borehole records. The number of records available is shown plus all of the vital statistics for this particular borehole.

Both the reports and the borehole records can be scrutinised by searching the database for particular records that contain user-defined data. Selecting **1, Site Investigations** from the Subject Screen (Figure A3) will lead to the following screen:

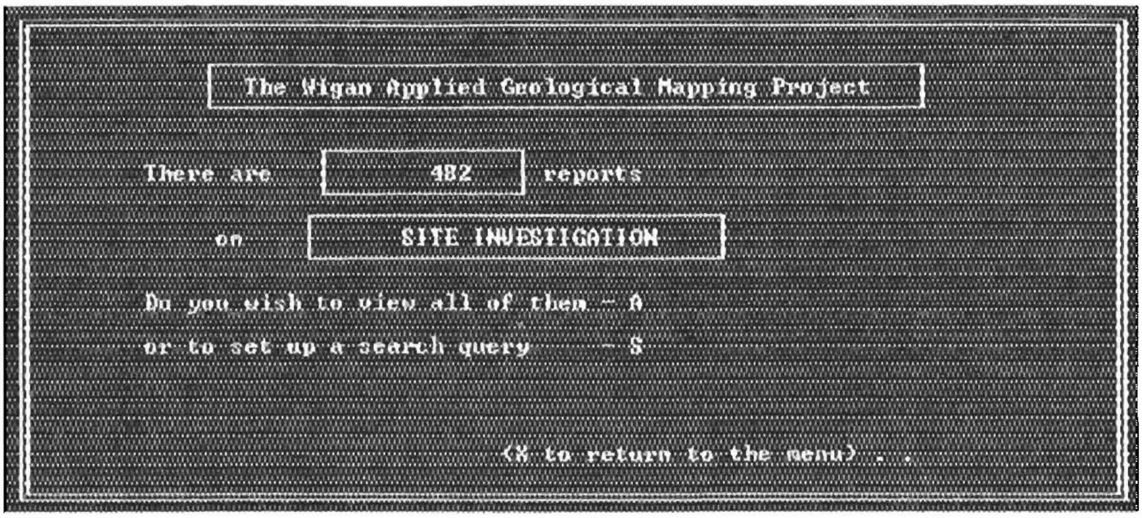

Figure A6 Search screen for site investigation.

Selecting the search option displays a new screen entry form (Figure A7) which allows the user to type any relevant data that may enable the computer to find such an occurrence within the database records.

Once the cursor is positioned over the exit box, the search can begin by giving an affirmative answer ('Y'). Supplying a no ('N') answer will enable the user to change an item on the form before initiating the search — returning an 'X' will cause this procedure to stop and the program returns to the main menu. Some areas, such as the date, enable the user to enter two dates and hence give a range from which the computer can search. In this case a search is carried out for any Site Investigations relating to 'Winstanley': (Figure A7).

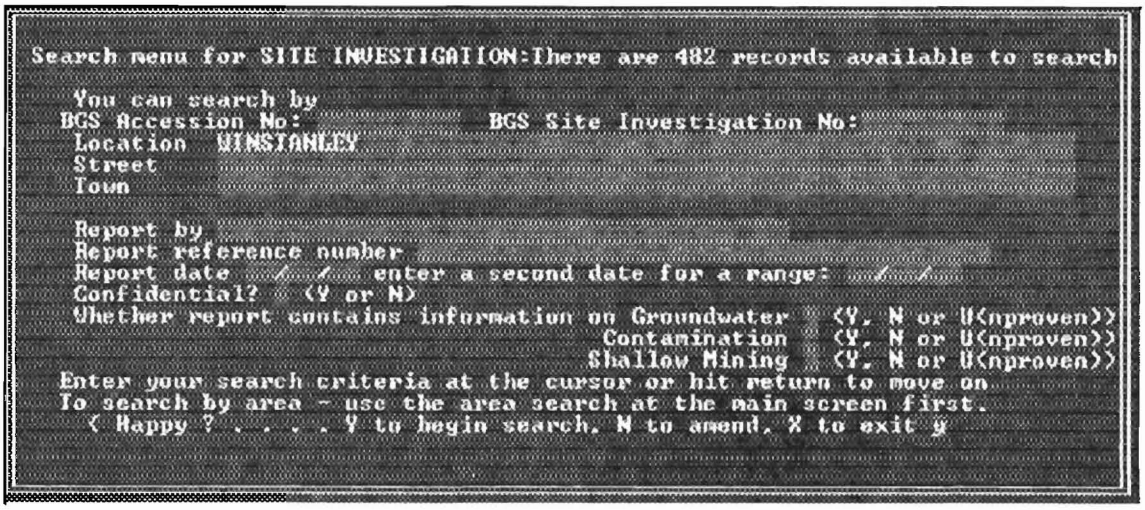

Figure A7 Result of subject search for reports.

Once the search has been carried out the records fulfilling the chosen criteria can be displayed on the screen:

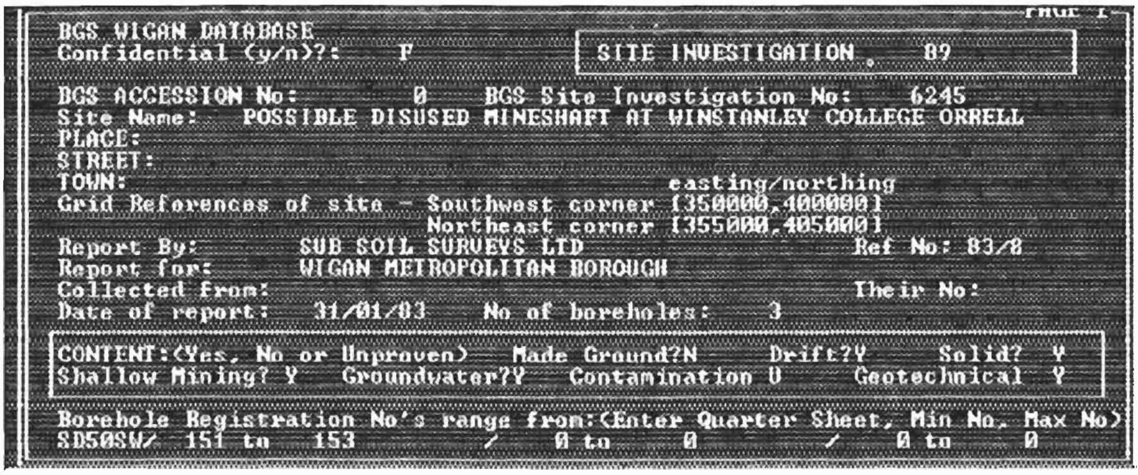

Figure A8 Two page screen report for Site Investigation record

Selecting **2. Area of interest** from the main screen (Figure A2) allows a search of the database using a defined geographical area of interest. The following screen will be displayed:(Figure A9).

To define an area of interest, the user must type in the grid references of the South-West and North-East corners of a rectangular area, as shown diagrammatically in Figure A9. Six figure numbers are required and the maximum/ minimum values of the Wigan area are given in brackets. The program will not allow nonsensical values, for example, outside the areas shown or where the NE corner is below the SW corner. Once these have been entered and confirmed with a 'Y' in the 'OK box' the program will sift through the records to find those which lie within the area.

Choosing a negative answer ('N') cancels the area search and returns the user to the main screen.

Once the program has sifted through the database and located records that lie within the chosen area, a new screen is displayed to give the result of the search.

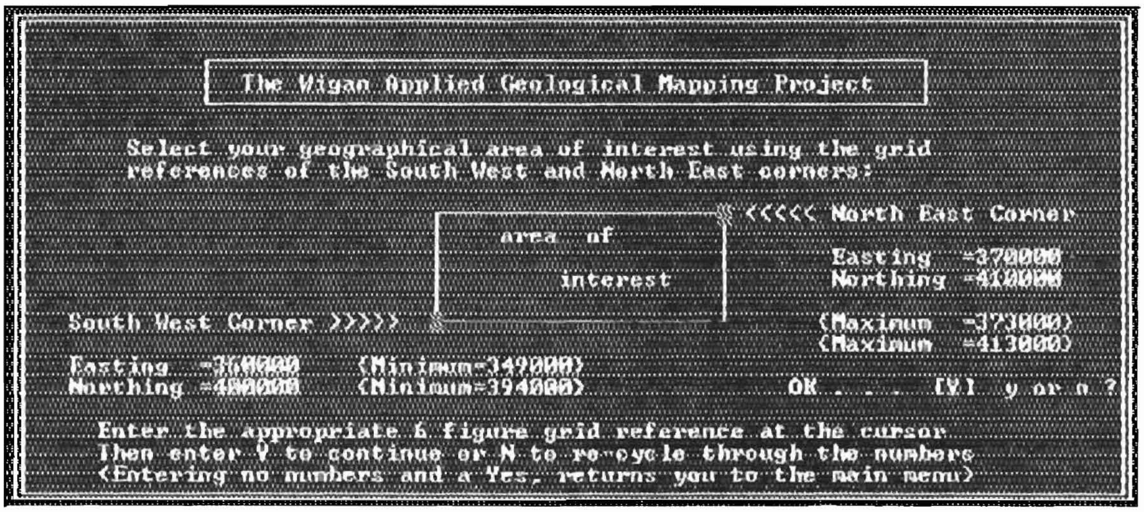

Figure A9 Area search screen.

The number of borehole and report records are given separately plus the wide choice of viewing these records, that is, to view all the borehole records or to search through them, to view all of the reports or to set up a search through them.(Figure A 10).

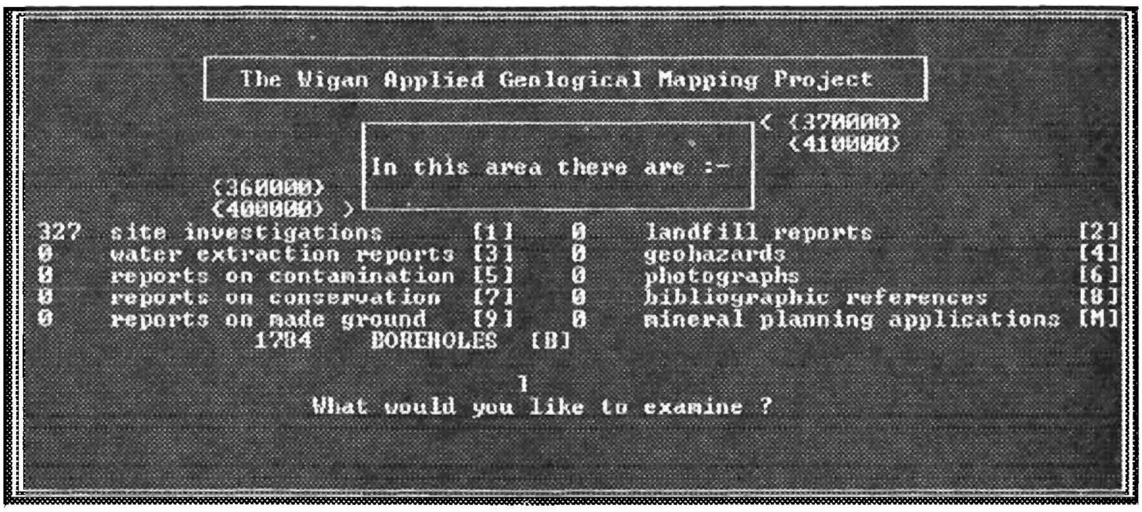

Figure A10 Result of area search.

As a reminder of the chosen area, the grid references are displayed at the edges of the results box. If there are no records in this area then the only option given is to return to the main screen.

The third option from the main screen is to append the records (Figure A2). This is the option that should be taken to enter data, one record at a time into the database or to change a record that is incorrect or needs to be updated. An example of a data entry screen for land fill is shown in Figure A11.

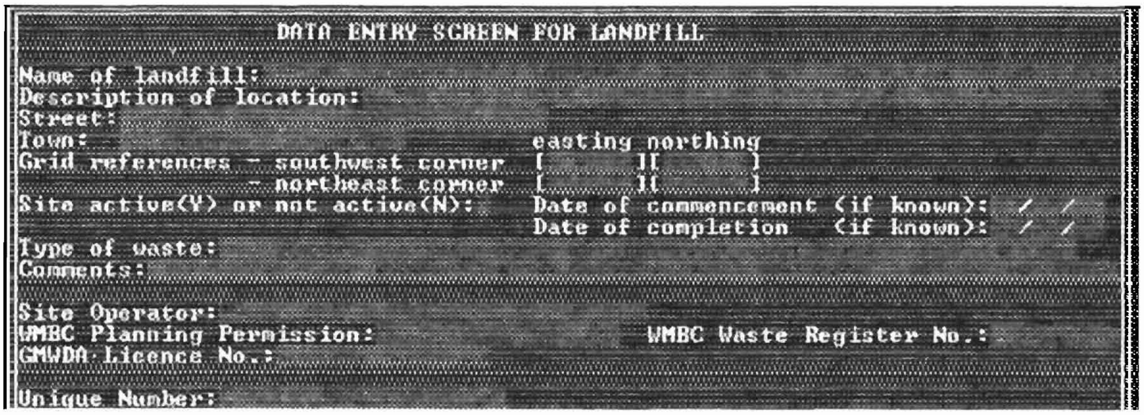

Figure A11 Entry screen for Landfill records.

The program allows each of the items to be edited using all of the usual cursor movement functions (for example, arrow keys, delete key etc).

Moving from record to record is achieved by the PageUp/PageDown keys. Trying to move up from the first item or below the last item on the current form will cause the preceding or next record to be displayed, respectively.

To enter data on a larger scale requires knowledge of dBase programming and notes can be found on this in the Programmer's Guide.

APPENDIX II

Details of opencast coal sites worked within Wigan MBC.

Name Reference Number	Seams worked	Old workings Volume of voids in yds^3 or post metrication m^3	Start	Finish	Restored	Comments
Albert 041674	Riding A Riding B Riding Ashclough Ashclough Bottom Leaf Park Yard Ince Yard Top Ince Yard Bottom Ince Deep Yard Top Ince Deep Yard Bottom	N N N Y 3 — Y 47 Y 6363 Y 8725 Y73 Y 99	1974	1975	1980	At the deep side old workings are 50 m below ground level. Possible continuation (unknown) to the deep and possibly along strike.
Beefold	Ince Yard Bin Tops Bin Bottoms	U U	1958	1959	1959	
Crab Fold 041585B	Ince Yard Bin Tops Bin Bottoms Crumbouke Brassey	N N N Y 8812 Y 66	1957	1958		Abundant old workings in Crumbouke. Minor old workings at end of Brassey workings.
Crow Bank 041543B	Brassey B & W	N Y 20555	1955	1956	1957	Abundant old workings — probably along strike extension.
Umberton	Black & White Trencherbone Rider Trencherbone	N N Y	1950	1957	—	Outside area. Almost totally worked.
Green Vale 641344B	Trencherbone	Y	1949	1950	—	Just on Wigan boundary. Abundant workings in Trencher.
Greenfield	Rams	Y 25785	1953	1954	—	Abundant old workings (75–80% extraction).Continue both down dip and along strike.
Shams NW 10 1188	Crumbouke	Y	1948	1948	—	Old workings encountered very close to previously known old workings.
Peelwood	Bin Bin Bottom Leaf	U U	1955	1956	1958	Unknown
Sandyforth Farm 1923	Flaggy Delf Top Flaggy Delf Middle Flaggy Delf Bottom King Top King Bottom Queen Top	Y 3 N N Y 28931 Y 28788 N	1985	1988	19??	Shaft only 4–29 m below ground level, worked together. Certainly extend along strike and down dip.
Windy Arbour 031070	Flaggy Delf Top Flaggy Delf Middle Flaggy Delf Bottom King Top King Middle King Bottom	N N N Y 3297 Y 3131 Y 15	1983	1984	1984	Randomly orientated roadways and pillars (not systematic). Workings begin at approximately 2 m below ground level (only up to 119 m AOD). Extend along strike and down dip. Shaft only in B. King.
Gladden Hey 041203B	Wigan 9'	Y 600	1971	1973	1974	Systematically laid out pillar and stall workings. Will extend along strike/down dip. Recorded workings to N.

Name Reference Number	Seams worked	Old workings Volume of voids in yds^3 or post metrication m^3	Start	Finish	Restored	Comments
Long Covert LA 1030	W2' W4'	U U	1944	1946	1946	
Blackrod I plus extension 041409 B	King Tops King Bottom Queen Plodder Tops Plodder Middle Plodder Bottom	Y 0725 Y 23951 N N N N	1955	1957	1958	
Blackrod II 041409	Upper King Little Mine King Top King Bottom Queen Plodder Top Plodder Middle Plodder Bottom	N Y 918 Y 34923 Y 31046 Y 3776 Y7185 Y 105 N	1957	1964	1965	Outside area
Harvey House Harvey House Extn. NW 10 1392 Hawkley Brook NW.10 1393C 041392D 041392C/D	Ince New Ince Yard Bulldog I4' Tops I4' Bottoms unnamed	 Y 4549 Y 132836	1947	1951	1951	Pillar and stall — not previously known — structure complex and highly faulted.
Burgess 031399	UNKNOWN	U				
Great Boys NW 10 1311	Bin Mine	Y (Bell pits)	1947	1948		Old workings closely follow strike. Bell pits down to certain depth (no levels).
Tan Pit Slip East 041679	 Park Yard Ince Yard Top Ince Yard Middle Ince Yard Bottom Roger Pemberton 2'	Ashclough Y 1852 Y 7752 Y 2024	1979	1980	1981	Dense stall and pillar from 5–11 m below ground level. Not up to crop. Continue along strike to west and down dip. Thickness: Top 0.70 m Middle 0.73 m Bottom 0.75 m
Derbyshire House II and Reed Lane 041200 B	Ince 7' Wilcox Top Wilcox Bottom Pemberton 2'	N N N N	1952	1953	1954	
Highfield Farm LA.1014	W9'	U		1944	1945	Probably old shallow workings from Summers Hall Colliery.
Ben Johnson Wheatlees Derbyshire House NW.10 1012 NW.10 1411 NW.10 1412	Ince 4' Tops Ince 4' Bottoms Ince 7'	N Y 108403 Y 47072	1951	1952	1952	Ince 4' — Very extensive old workings from just below crop down to approximately 60' below ground level (90' AOD) (continue down dip) Ince 7' — From just below crop to max depth of working.
Reed Lane II	P 5' P 2'	N N	1958	1960		No old workings.

Name Reference Number	Seams worked	Old workings Volume of voids in yds^3 or post metrication m^3	Start	Finish	Restored	Comments
Tan Pit Slip 5th Extn 041682	W 4' W 2' Trencherbone Upper King Lower King	Y 3373 N Y 250 Y 2409 Y 2922 Y 109	1978	1979		W 4'Average pillar size 9 × 2 m Trencherbone and below — Randomly orientated pillar and stalls.
Crows Nest 041227	King Top King Bottom Queen	U U U	1947	1946	1947	
Park House Farm Ince	7' ?	Y	1942	1943		Small area of old workings.
Landgate Site Hawkley Hall	Ince Park Wilcox Tops Wilcox Bottoms Pemberton 4'	U Y 406 Y 976 Y 868	1946 1954	1942 1955		
Tan House	Queen King Top King Bottom	U U U	1944	1946		
Gustavus Hillock NW 10 1018	W 4' W 9' W2'	Y Y Y	1947	1947		
Drummers Fields I, II NW10.1073	W 9' W 2' plus 4' N	N Y	1945	1946		 Minor
Red Rock	Bargan P 5' P 2' P 4'	U U Probably N U U	1953	1955	1956	
Grimshaw and Brock Mill 041566B 041084B	Park Yard Ince Yard Bulldog Ince Depth Yard Ince 4' Ince 7' Bargan P 5' P 4' Upper King Cannel King Tops King Bottoms Queen	N Y 569 U U U Y 2772 U U U U Y 43067 Y 342 Y 120 U	1955	1959		
Standish LA/10/64 A–J	Ince 4' Ince 7' Ince Depth 7'	U				Old `areas worked' plan only. No evidence for old workings.
Frudsmans Brook	Ince Deep Yard ? Ince Deep Yard ?	U U				
Hermitage	Bulldog ?		1934	1945		Old workings previously encountered in drilling

Name Reference Number	Seams worked	Old workings Volume of voids in yds^3 or post metrication m^3	Start	Finish	Restored	Comments
Astley A LA to 83 Astley B LA to 83A Astley Cannel 50 m 83C Astley D & E 83B ?	? ?	U	1944	1945		
Wakefield NW 10 88 Patchroft	Ince 7' Ince 4' Haigh Yard King Top King Bottom Queen	U Y Y Y	1948 1951 1944	1950		
Slackey Fold 041057	P 5' B 7'	Y 2912 Y 27346	1952	1953	1953	Workings continue down dip and along strike.
Winstanley II Winstanley II Winstanley IIIA & IV Windy Arbour 031070	W 5' W 5' W 5' W 4' W 2' Ravine W 9' Top W 9' Bottom W 2' W 4'	U Y N U U U U U U	1944 1944 1949 1951	1945 1946 1951 1952	 1951	W 5' — Worked near crop in North, unworked to South.
Chair Wood M plus Pleasant Orretts House	Sir John Flaggy Delf King Queen Ravine Arley	U U U U U U	1947	1953	1954	No old workings shown on completion plan but very old site?
Millington Barton Clough III 0411094B	Ravine Orrell Yard Tops Orrell Yard Bottom	 Y 7427 Y 891	1953	1955		Orrell Yard Tops. Continue down dip and along strike.
TAT Windy	Sir John Flaggy Delf King Tops King Bottoms Queen	U U U U U	1956	1961		
Parton Clough 2	Ravine	N	1946	1948	1950	
Lower Castel	Flaggy Delf King Queen Ravine Orrell Yard	N N N N N	1950	1951	1952	
Chapel House and Hump Farm II	Flaggy Delf King Queen	N N N	1955	1956	1958	
Leyland Green	King Top King Bottom Queen	N N N	1945			
Baxter	King Queen	U U	1945	1945		

Name Reference Number	Seams worked	Old workings Volume of voids in yds³ or post metrication m³	Start	Finish	Restored	Comments
Bryan Gates 041622	Top Pemberton 5' Pemberton 2' Pemberton 4' Bickershaw 7' Little Roger Stony Roger Higher Middle	N N N Y 4866 Y 34886 N Y 987 N N				P4' minor but possibly extend. Bickershaw 7' very extensive Stony Roger minor.
Mill Farm	Top Middle Bottom	N N N	1956	1957		
Tanpit Slip 041578	Ashclough Park Yard Top Ince Yard Bottom Ince Yard Crumbrouke	Y 3 shaft N Y 4 shaft Y 1833	1976	1978		
Double Nougat	Pemberton 5' Pemberton 2'	Y 314 N	1955	1955		