TECHNICAL REPORT WA/96/1

A geological background for planning and development in the City of Bradford Metropolitan district

Volume 2: A technical guide to ground conditions

Editors: C N Waters, K Northmore, G Prince and B R Marker

Authors: C N Waters, K Northmore, G Prince, S Bunton, A Butcher, D E Highley, D J D Lawrence and C P M Snee

BRITISH GEOLOGICAL SURVEY
In association with
ENTEC UK LIMITED

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

Bibliographic reference

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Keyworth, Nottingham British Geological Survey

BRITISH GEOLOGICAL SURVEY

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The Survey publishes an annual catalogue of maps, which lists published material and contains index maps for several of the BGS series.

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1 Preface

This report was produced and should be used in conjunction with the accompanying Volume 1: 'A guide to the use of earth science information in planning and development', and the set of thematic geological and planning maps. These present the results of a study, commissioned and funded by the Department of the Environment (contract PECD 7/1/460), carried out between 1993 and 1996. The aim of the research was to develop techniques for the synthesis and presentation of earth science information in a precise and accessible form for use by planners and developers to provide a general introduction to the geological factors most relevant to planning and development. The report may also be used to provide background information for the preparation of desk studies for specific developments within the study area of the City of Bradford Metropolitan District.

The study represents one of a series of research projects, commissioned by the Department of the Environment, for urban coalfield areas in the UK, including Morpeth–Bedlington, St. Helens, Castleford–Pontefract, Coventry, Nottingham, Wrexham, Black Country, South Leeds and Wigan.

The study area encompasses the entire area of the City of Bradford Metropolitan District, which is covered by 28 Ordnance Survey 1:10 000-scale topographic maps and by parts of three 1:50 000-scale geological sheets, Bradford (69), Huddersfield (77) and Clitheroe (68). The project was concurrent with a full revision of the geological maps of the District, at 1:10 000-scale, funded and undertaken by BGS. The project involved the collection and collation of a wide variety of archival information. As part of the study, new data were collected by the BGS Engineering Geology and Geophysics Unit on landslips and by Chris Snee, University of Bradford Civil Engineering Department, on sandstone building stone properties.

The report presents the views of the authors, which may not necessarily be those of the Department of the Environment or the Local Authority.

2 Executive summary

This volume is the second of a two part report entitled '**A Geological Background for Planning and Development in the City of Bradford Metropolitan District**'. The report presents the results of a project carried out by the British Geological Survey, in association with Entec UK Ltd, between 1993 and 1996, which was commissioned and funded by the Department of the Environment. The principal aim was to develop techniques to improve the synthesis and presentation of geological information relevant to planning and development, using the City of Bradford Metropolitan District as the study area.

The two volumes of the report are aimed at distinct readerships.

Volume 1: A Guide to the Use of Earth Science Information in Planning and Development is aimed at use by planners and developers, with emphasis placed on the relevance of earth science issues to the local planning system.

Volume 2: A Technical Guide to Ground Conditions is aimed at use by specialists with technical knowledge in the fields of geology, engineering geology, hydrogeology, mineral resources or conservation.

These reports are accompanied by a series of eight thematic maps. Map 1 is a summary map to be used, in conjunction with Volume 1 of the report, by planners and developers as a key to identify the main issues relevant to the use of land in the District. The remaining maps are aimed for use by specialists in the fields of earth sciences and should be used with reference to relevant sections of this volume of the report. The maps are as follows:

Map 1 — Earth Science Factors Relevant to Planning and Development
Map 2 — Bedrock Geology (two parts for north and south of District)
Map 3 — Superficial Deposits (two parts for north and south of District)
Map 4 — Mineral Resources and Surface Mineral Workings
Map 5 — Mined Ground and Shafts
Map 6 — Slope Steepness and Landslips
Map 7 — Engineering Ground Conditions (additional maps for foundation conditions, suitability as engineered fill, excavatability and thickness of natural superficial deposits)
Map 8 — Water Resources and Flooding

Copies of the report and maps can be obtained from the British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG. Archival data are held at the same address.

In addition, five computer databases provide index information on borehole records, site investigation reports, landslips, landfill sites and sandstone quarries.

Limitations

This report aims to provide a general introduction to the geological factors relevant to planning and development in the District, and as a background for those preparing desk top studies of specific sites. The report and associated thematic maps provide information which 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.

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

The study area

The study area comprises the entire area of the City of Bradford Metropolitan District, West Yorkshire (Figure 1). The District covers an area of about 400 km^2, of which about 30% is urban. The remainder comprises agricultural land, peripheral to the urban areas, and upland moors present in the west and north of the District.

The rapid growth of the urban areas during the Industrial Revolution, in the 18th and 19th centuries, reflects the expansion in the textile industry and heavy industry, such as iron and steel works. This development was facilitated by the local source of mineral resources, such as sandstone, coal, fireclay, ironstone, clay, and sand and gravel. Urban and industrial expansion was closely linked to the improvement of transport networks, in particular canals in the 18th Century, railways in the 19th Century and roads in the 20th Century. Despite a decline in the importance of the textile industry, mineral exploitation industries and the heavy industries during the 20th Century, the District has undergone regeneration over the last few decades, built on the increased importance of light industry, service industries, financial businesses and tourism.

Sources of information

The information used in this study was acquired from numerous sources. These data include maps, memoirs, aerial photographs, borehole and trial pit records, site investigation data, hydrogeological and hydrological data, abandonment mine plans and library references. A comprehensive list of organisations and companies which provided data for use during the project is provided in the appendix.

The study funded the collection of new data on landslips and building stone properties. The landslip data were produced by BGS engineering geologists, the building stone data were produced by the University of Bradford Civil Engineering Department and BGS Geochemistry Unit. In addition, concurrent with this study, BGS funded and carried out a full geological resurvey of the District, producing a comprehensive set of 1:10 000-scale geological maps (Figure 2) and accompanying technical reports, listed in Appendix 14.4. These maps and reports may be purchased from Map Sales, BGS Keyworth.

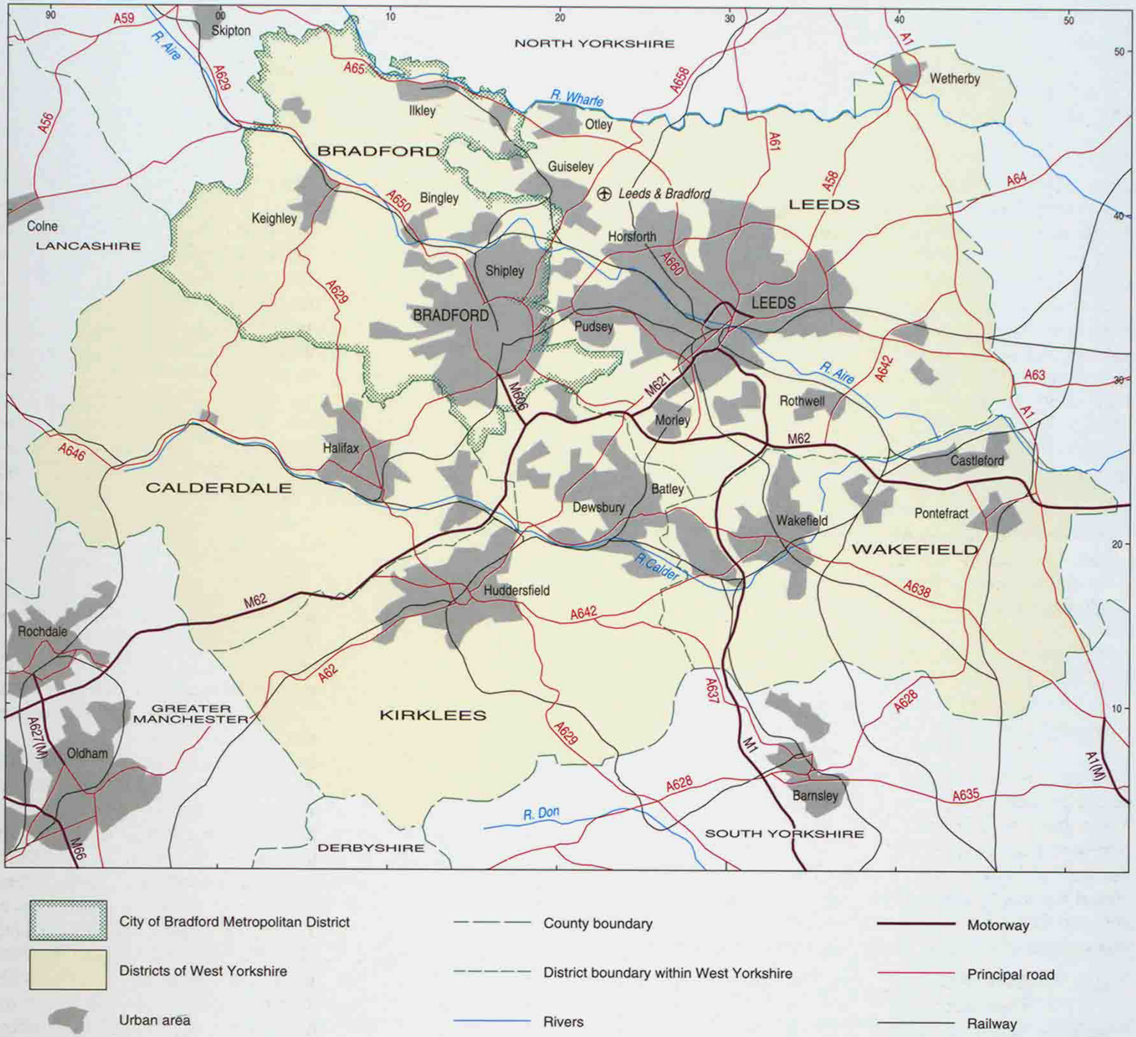


Figure 1 Map of West Yorkshire showing the location of the City of Bradford Metropolitan District and distribution of urban areas and main transport routes.

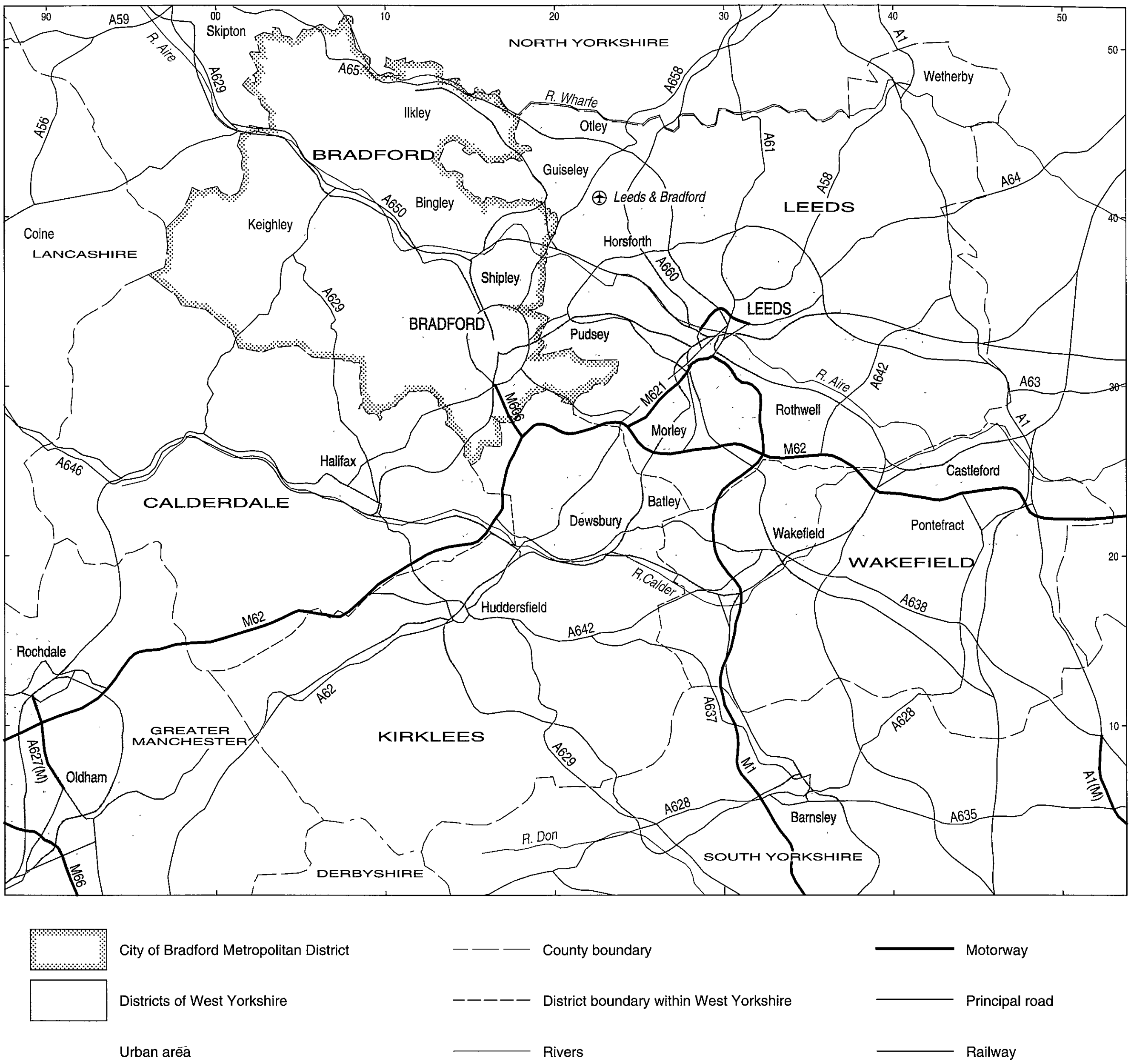


Figure 1 Map of West Yorkshire showing the location of the City of Bradford Metropolitan District and distribution of urban areas and main transport routes.

Geology

The bedrock geology of the District include predominantly sandstone, siltstone, mudstone and subordinate coal, seatearth and ironstone of the Millstone Grit and Lower Coal Measures. These sedimentary rocks were deposited about 310–315 million years ago, during the Carboniferous period. In the late Carboniferous a phase of deformation, part of the Variscan Orogeny, resulted in the development of a complex network of faults across the District.

Over much of the District, the bedrock geology is overlain by poorly consolidated drift deposits. These comprise Quaternary glacial deposits, including Till (boulder clay), Hummocky Deposits (moraine), Glaciofluvial sand and gravel and Glaciolacustrine clays and silts, and periglacial or post-glacial deposits such as Head, Peat, Alluvium, Alluvial Fan Deposits and River Terrace Deposits. Drift deposits may locally exceed 50m in thickness within buried channels present in Wharfedale and Airedale.

Parts of the District are covered by man-made deposits, which overlie both the bedrock and drift deposits. These man-made deposits comprise Made Ground and Infilled Ground, much of which is derived from the mineral and heavy industries formerly prevalent in the District. This report links large areas of man-made deposits to former and current land-use, in order to give an indication of the possible composition of the deposits.

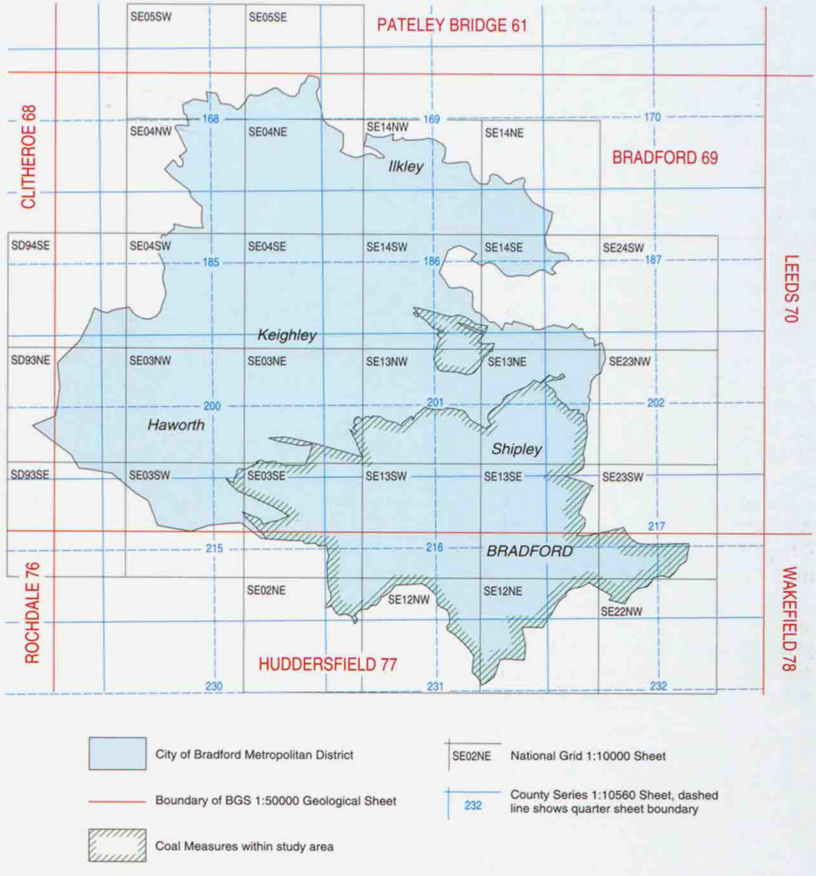
The report discusses the nature of the common soil types in the District and identifies conservation sites, with discussion of the relevance of these sites to earth sciences.

The bedrock geology, the nature and thickness of natural drift and artificial (man-made) deposits, soils and conservation issues are discussed in **Chapter 6** of this volume.

Mineral resources and mined ground

The District has had a long history of extraction of mineral resources, including surface workings in sandstone,

Figure 2 Distribution of Ordnance Survey maps and geological maps for the City of Bradford Metropolitan District.



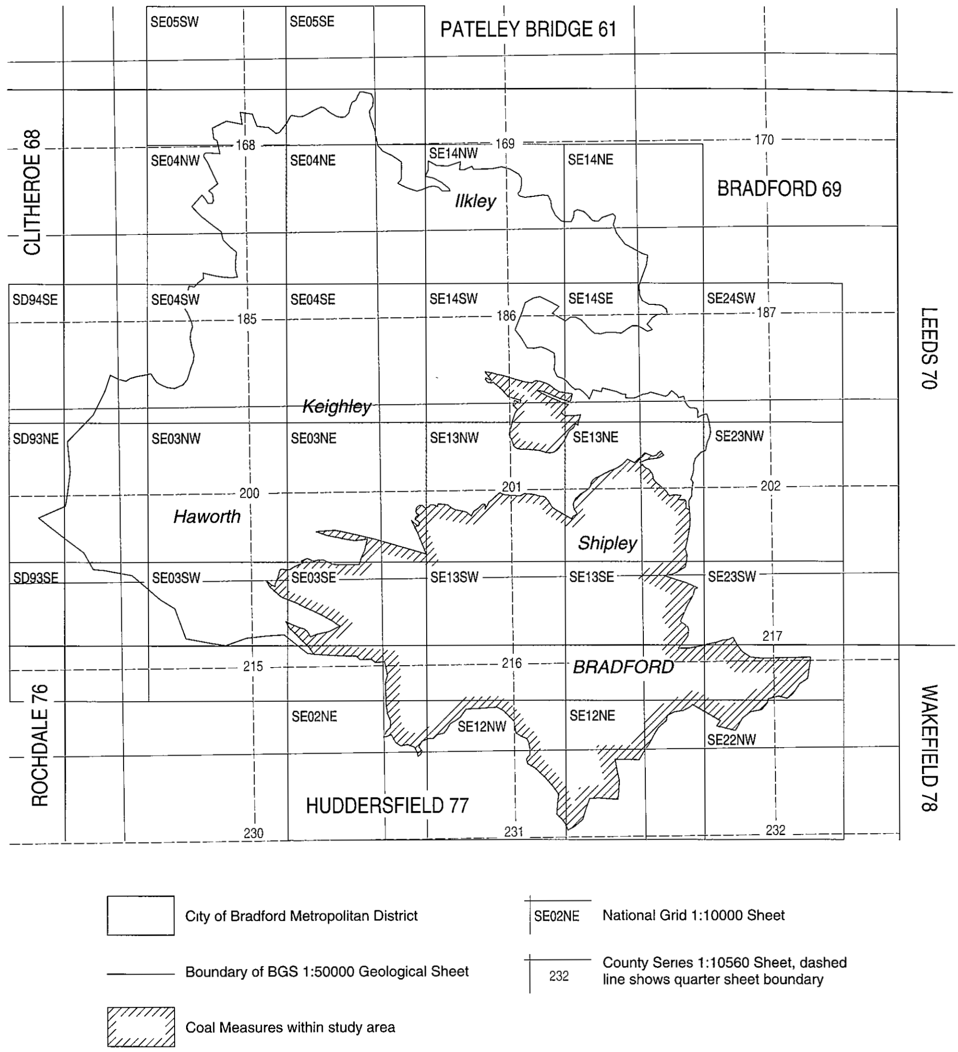


Figure 2 Distribution of Ordnance Survey maps and geological maps for the City of Bradford Metropolitan District.

brick clay, sand and gravel, peat and limestone, with minor opencasting of coal, and underground mining of coal, fireclay, ironstone, and to a lesser extent sandstone. Surface extraction of sandstone, with 12 working quarries, and fireclay, with one working pit, are the only mineral resources currently worked in the District. However, near-surface deposits of coal and sand and gravel represent potentially exploitable resources. The extent of the principal mineral resources are discussed fully in **Chapter 7** of this volume.

The legacy of underground mineral extraction in the District is the presence of numerous mine entries, including adits and shafts, and extensive areas of urban Bradford known to be underlain by former workings. However, many old workings are poorly documented and it is possible that unrecorded shallow workings and mine entries may exist. Voids created during mining often collapse soon after the mineral has been extracted. However, some shallow workings may remain open and have the potential to collapse and cause surface subsidence. The mining methods employed for extraction of coal and sandstone, and the relevance to mining subsidence are discussed fully in **Chapter 8** of this volume.

Slope stability and engineering ground conditions

The steep slopes present on many valley sides in the District result in potential slope instability. The abundance of mapped landslips in the District indicate the prevalence of past slope failure, with a number of the landslips considered to be still active. This report identifies in **Chapter 9** the principal types of slope failure, their distribution and causes and indicates measures which should be undertaken to ensure that future development does not cause slope failure.

Potentially difficult ground conditions may result from the weathering of bedrock, in particular from areas of faulted ground, and from areas of soft ground associated with some drift deposits, including Peat, Glaciolacustrine clays and Alluvium. Of great significance in the District are the man-made modifications, both to the ground surface and sub-surface. Man-made deposits are often heterogeneous, may contain open voids, and may be susceptible to differential compaction, particularly in areas of fill into former excavations. Excavation and removal of material, either for mineral workings or for engineered constructions, may generate instability in previously stable deposits. Sub-surface excavations can also result in ground instability at the surface.

The suitability of bedrock and superficial deposits as foundations, as engineered fill and their excavatability are discussed in **Chapter 10** of this volume. The report reviews the effects of human modification of the ground and discusses measures required to identify potential problems and to permit safe development of sites.

Water resources and flooding, leachates and gas emissions

The District's public water supply is derived from a series of reservoirs, located both in the west of the District and outside the District in North Yorkshire. Small volumes of groundwater are also abstracted, both as potable water for private consumption and as a supply to local industries, in particular textile manufacturers. The report discusses in **Chapter 11** issues associated with the abstraction and quality of both surface and groundwater, with information provided on the nature of the principal aquifers in the District. Of particular significance is the recharge potential of aquifers and the possible contamination of groundwater through the generation and migration of leachates derived from man-made deposits. Problems associated with the decrease in industrial abstraction of groundwater in the District this century, and the resultant potential for rising groundwater may cause problems for the foundations of buildings, flush leachates from landfill sites or cause acid mine drainage to issue at the ground surface.

Flooding is recognised as an historical problem in Airedale and Wharfedale and information is provided in **Chapter 11** on recent remedial measures and the establishment of protected washland areas, prone to flooding.

The potential hazards associated with toxic leachates and dangerous gases derived from waste disposal sites, gases derived from abandoned colliery workings and naturally produced radon gas are discussed in **Chapter 12** with an indication of possible remedial measures. For all areas with potential problems with toxic leachates or hazardous gases, an emphasis is made on the necessity of appropriate site investigations to be carried out prior to any development.

References, glossary and appendices

This report contains a comprehensive reference list and glossary of terms used, together with appendices providing information on the the main data sources, mineral industry operators, licenced groundwater sources, available geological and topographical maps and the results of the building stone properties study. A user guide and explanation of the data presented in the five computer databases, namely borehole records, site investigations, landfill sites, landslips and sandstone quarries, are also presented.

Notes

All National Grid references given in this report lie in the 100 km squares SE and SD (Figure 2). Grid references to specific sites are given to eight figures (accurate to within 10 metres); more general locations are given to six or four figures.

Each borehole record, site investigation report, landfill site, landslip or sandstone quarry, presented in the computer databases is prefixed by the code of the National Grid 25 km^2 area upon which the site falls, e.g. SE 13 SE. For each database, each record is given a unique registration number, in the form SE 13 SE/27.

3 Statement of limitations

The use of this report

This work is based on geological maps resurveyed in 1993–1994 as part of the BGS revision mapping programme. The maps were produced by extensive field resurvey, used in conjunction with aerial photographs, site investigation reports, mine plans and other reports which were collected by, or made available to, the project. 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.

The publication dates of the revision maps are shown in Appendix 14.4 and information collected subsequent to these dates may not have been taken into consideration. Other data may exist, not available to the project, which would add to the information shown on the maps. It is possible that there are features in the area, such as old shallow mine workings or infilled quarries, for which no record was made at the time of operation, 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 databases 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, technical reports and the original field slips from the geological survey of the area. Data used in the preparation of the reports and thematic maps are held by the National Geological Records Centre, BGS Keyworth, and, with the exception of confidential records, can be consulted by prior arrangement. Attention is also drawn to other sources of information and advice which should be consulted, a comprehensive list of which are provided in Appendix 2 of Volume 1 of the report.

4 Introduction

Aims and objectives

This report presents the results obtained during a three year research contract, Reference PECD 7/1/460, commissioned and funded by the Department of the Environment in 1993. The work was carried out by the British Geological Survey (BGS) in collaboration with Entec UK Limited (EUL). The BGS carried out the geological aspects and thematic map production and EUL were responsible for the planning aspects.

The aim of the research was to develop techniques for the synthesis and presentation of earth science information in a form which can be readily and directly used by planners and developers, as well as those with interests in conservation. The study area of the City of Bradford Metropolitan District comprises both an urban coalfield area, which has suffered industrial decline and regeneration over recent decades, and large areas of open moorland. This diversity of environments is reflected in a broad range of planning and development issues for which earth sciences are relevant.

The research aimed to provide advice, presented at a level appropriate for use in strategic planning, and to provide a regional context for site investigations. The research was not to be site-specific, though issues which may be relevant to the development of sites were to be identified. The databases prepared for the research have the potential to provide a long-term resource for planning and development in the area.

The broad objectives of the study were:

- to collect and collate available earth science data and information of relevance to planners, developers, engineers and conservation interests
- to organise the information in a form in which it can be retrieved and linked to digital mapping facilities for the purpose of this research and can be used subsequently, outside the terms of this contract, in responding to localised enquiries
- to identify sites of geological and geomorphological importance in addition to those already recognised as Sites of Special Scientific Importance or as Sites of Ecological or Geological Importance
- to produce a set of thematic maps on applied geological topics of relevance to land use planning, development and conservation in the study area
- to produce a derived summary map of the main planning considerations applicable to the study area
- to produce two reports, aimed respectively at non-specialists and to those with specific technical knowledge in the fields of geology, hydrogeology, engineering geology and mineral resources
- to advise on further requirements for research
- to develop new and innovative approaches to the management and presentation of earth science data
- to disseminate the results to a wide audience of users, particularly those with an interest in planning and development in the study area.

Information sources

The project was restricted to the collection and collation of existing data, with the exception of a landslip study carried out by engineering geologists and a study to determine the geotechnical properties of the main building stones in the District, produced in collaboration with the University of Bradford Civil Engineering Department. However, the project was concurrent with a full revision of the geological maps of the District, at 1:10 000-scale, funded and undertaken by BGS. The revision involved both field resurvey and the interpretation of data held in BGS archives, in addition to the data and information collected as part of the applied geological mapping project.

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 types used in the study and their sources are shown in Table 1. Full details of the source organisations are provided in the technical appendices (Appendix 14.1).

Databases

A database of the information collected during the project was compiled using dBase III+ software. The database was designed to be capable of collating information as an aid to cost-effective interpretation and thematic mapping and also to be capable of subsequent maintenance and updating, after completion of the study, to assist in the response to enquiries about specific sites.

The database provides summary information on five themes:

borehole and trial pit data
site investigation reports
landslips
landfill sites
sandstone quarries

A database user's guide is included in Appendix 14.6. This contains guidance on the use of the database. Copies of the database are held by the British Geological Survey, the Department of the Environment and City of Bradford Metropolitan Council.

Table 1 The main sources of data used during the study.

	BGS	CBMC	HETS	OS	BC	MVO	NRA	WRA	CEC	DoE	UoB
Topographic maps				*							
Geological maps & notebooks	*										
Landslip data	*								*	*	
Borehole records	*	*	*		*				*		
Aerial photographs		*									
Hydrogeological data	*						*				
Library holdings	*	*								*	
Geophysical data	*										
Abandonment mine plans & mine entries	*		*		*	*			*		
Landfill data	*	*						*			
Unitary Development Plan		*									
Sandstone properties	*										*

BGS	British Geological Survey
CBMC	City of Bradford Metropolitan Council
HETS	Highways, Engineering & Technical Services Joint Services Committee
OS	Ordnance Survey
BC	British Coal (now held by Coal Authority)
MVO	Mineral Valuers Office
NRA	National Rivers Authority
WRA	West Yorkshire Waste Regulation Authority
CEC	Civil Engineering Consultants
DoE	Department of the Environment
UoB	University of Bradford

5 Thematic maps

Introduction

The results of the study are presented on a summary map of the Planning and Development Issues (Map 1) and seven thematic geological maps (Maps 2 to 8) showing at 1:25 000- or 1:50 000-scale aspects of the geology of the District relevant to planning and development.

Map number and theme	Scale
1. Earth Science Factors Relevant Planning and Development	1:50 000
2. Bedrock Geology (2 maps)	1:25 000
3. Superficial Deposits (2 maps)	1:25 000
4. Mineral Resources and Surface Mineral Workings	1:50 000
5. Mined Ground and Shafts	1:25 000
6. Slope Steepness and Landslips	1:50 000
7. Engineering Ground Conditions	1:50 000
7A Foundation Conditions	1:100 000
7B Suitability for Engineered Fill	1:100 000
7C Excavatability	1:100 000
7D Drift thickness	1:100 000
8. Water Resources and Flooding	1:50 000

The user should consult the User's Responsibility printed on each map, which provides a statement of their limitations; this is expanded upon in Chapter 3 of this report.

Map 1 should be used in conjunction with the non-specialist report 'A user's guide to planning and development', whereas Maps 2 to 8 should be used in conjunction with the technical report aimed for specialists, 'a technical guide to ground conditions'. Table 2 is a flow chart showing how the 'Planning and Development Issues' map can be used as a key to identifying which thematic geological maps and chapters in the technical report need to be consulted for further information.

The thematic geological maps should be used in conjunction with the databases created for this project. These include boreholes and trial pits, site investigation reports, landslips, landfill sites and sandstone quarries. The databases are discussed more fully in Chapter 4 and Appendix 14.6.

Earth science issues relevant to planning and development (Map 1)

This map provides a summary of the information presented on the seven thematic geological maps. This map is intented to provide planners and developers with an insight into the most important potential geological problems which may affect an area under consideration for planning or development. The map can be used as a key to indicate which

Table 2 Flow chart showing how map 1 (Earth science factors relevant to planning and development) can be used to identify which thematic maps and chapters in both volumes of the report need to be consulted for further information.

Earth Science Factors relevant to Planning and Development (Map 1)

Factors	Vol. 1 Chapter	Thematic Map	Vol. 2 Chapter
Variable Man-Made Ground Conditions	4.2	3 & 7	6, 10, 11, 12
Known or Potential Undermined Ground	4.3	5	8, 10, 11, 12
Mineral Resources	4.4	4	7
Surface Mineral Workings	4.5	4	7
Geological Faults	4.6	2	6, 9, 10, 11, 12
Landslips	4.7	6	9
Water Resources	4.8	8	11
Washland and Flood Protection	4.9	8	11

of the thematic geological maps should be consulted to ascertain the availability of more technical information. The map can also be used in conjunction with the policy plans for the Unitary Development Plan of the District.

Bedrock geology (Map 2)

This map displays the bedrock (solid) geological units of the Millstone Grit and Coal Measures at outcrop, either at surface or at rockhead beneath superficial deposits. The position of important coal seams and structural data, including faults and the dip of strata, are shown. The superficial deposits, including drift and man-made deposits, are not shown. The extent of landslip deposits is presented, though no attempt has been made to distinguish between landslips entirely within man-made deposits, drift or affecting the bedrock. The geological sequence, with approximate thicknesses, is shown in the Generalised Vertical Section. The lithologies present in this sequence are described briefly in Chapter 6 of this volume and in more detail in the relevant Technical Reports for the component 1:10 000-scale sheets.

Superficial deposits (Map 3)

This map shows the distribution of superficial deposits, including both natural drift and artificial (man-made) deposits. The nature of these deposits is described briefly in Chapter 6 of this volume and in more detail in the relevant Technical Reports for the component 1:10 000-scale sheets. The boundaries of these deposits are generally conjectural.

Only the drift deposits present at the surface are shown; they may be underlain by, or interdigitate with, other drift deposits at depth. The extent of landslip deposits are shown, though no attempt has been made to distinguish between landslips entirely within man-made deposits, drift or affecting the bedrock. Undifferentiated bedrock is shown where the drift deposits are either absent or less than a total of 1 m thick. The drift thickness is shown as a series of contours (isopachyte lines) at 5 m intervals. The contours are largely derived from borehole data and, consequently, there is considerable uncertainty as to drift thicknesses where such data is sparse.

Artificial (man-made) deposits are shown only where the deposit is 1.5 m, or more, in thickness. The boundaries shown on the map are often conjectural. These often heterogeneous deposits are divided into Made Ground, deposited on a natural surface and Infilled Ground, deposited within an excavation. The map does not categorise the deposits by their content. However, the map does provide an indication of the current, or former, land-use associated with significant areas of man-made deposits, which may be used as an indication as to their possible composition.

Further information on the nature of many landfill sites in the District is contained in a database (see Appendix 14.6), which should be used in conjunction with the map.

Mineral resources and surface mineral workings (Map 4)

This map shows the extent of surface mineral resources and the location of the main active and disused quarries or pits. Quarries and pits which have been largely, or wholly, backfilled are not shown; they are presented on Map 3.

Map 4 presents the resource areas for sandstone and sand and gravel. The extent of the sandstone resource, derived from the information presented on Map 2, represents those sandstones which are currently or have historically been most extensively worked in the District. The map does not attempt to show the quality or thickness of the resource. However, the map shows the localities at which samples for the building stone properties database (see Appendix 14.5) were collected. The map also shows the entries for the sandstone quarry database. The extent of sand and gravel resources, present as drift deposits, is derived from data presented on Map 3.

Only the known area of surface, or near surface, coal workings are shown on Map 4. The approximate location of the principal coal seams at crop, or sub-cropping beneath drift deposits, is shown on Map 2. The distribution, thickness and quality of fireclays and brick clays are laterally variable and it is therefore not possible to show the extent of the resource on the map.

The mineral resource potential in the District is discussed fully in Chapter 7 of this volume.

Mined ground and shafts (Map 5)

This map shows information regarding known workings and shafts or adits for coal (together with fireclay and ironstone) and sandstone. The extent of known coal workings has been subdivided into workings at less than, or greater than 30 m depth below ground surface. The outline of the maximum extent of undermined areas is generalised and approximate at this scale and should not be relied upon for site investigation purposes. The map also depicts the generalised outcrop area of Coal Measures with coal considered to be workable by underground methods at less than 30 m below ground surface, for which no underground workings are recorded. For this area, the location of site investigation records which have proved workings are shown.

The map shows only the extent of known underground sandstone workings. However, records of the extent of these workings are rare. Where such sandstones occur at the surface (shown on Map 2), the possibility of unknown underground workings should be taken into consideration.

The approximate location of abandoned mine shafts and adits for coal and sandstone workings are shown. The positions are generalised and should only be used as a guide to the density of shafts in an area. No reliance should be made on the accuracy, completeness or reliability of the locations. The extent of abundant, closely spaced bell pits and associated crown-holes are shown as an area with approximate boundaries.

More details on mining methods and the relevance to subsidence are given in Chapter 8 of this volume.

Slope steepness and landslips (Map 6)

This map shows areas of steep slopes and known landslips. The slope steepness contours are generated from the Ordnance Survey Digital Terrain Model, with the slope steepness categories considered to represent angles of slope with significance to development. An insert figure presents a perspective view of the topography of the District. The extent of landslip deposits are the same as shown on Maps 2 and 3. For further information on the landslips, the landslip database should be consulted.

This map should be used in conjunction with the Engineering Ground Conditions Map (Map 7), which outlines the geotechnical properties of the lithologies or deposits. Details of the types and causes of slope failure are provided in Chapter 9.

Engineering ground conditions (Map 7)

Map 7 shows the distribution of the engineering geological categories of bedrock and superficial deposits and provides a summary of the geotechnical properties. The engineering geological categories are cross-referenced to the bedrock lithologies and superficial deposits shown on Maps 2 and 3, respectively. Where man-made deposits or landslips are present, the underlying engineering geological unit is presented. Where drift deposits are greater than 5 m in thickness, derived from Map 3, only the nature of the engineering soil unit is shown. Where drift deposits are 1 to 5 m in thickness, both the nature of the engineering soils and underlying bedrock are shown. Only the nature of the drift deposit at surface is shown; it may be underlain by other drift deposits at depth. The location of faults at outcrop, derived from Map 2, and areas where coal or sandstone undermining may occur within 30 m of ground surface and result in localised subsidence, derived from Map 5, are also shown. Both major faults and areas of mine-related subsidence may change significantly the geotechnical properties of the bedrock.

Aspects of the Engineering Ground Conditions are also presented on maps 7A to 7C, namely Foundation conditions (7A), Suitability as engineered fill (7B) and Excavatability (7C). Map 7D is a summary of the drift thickness information shown on Map 3.

The Engineering Ground Conditions maps should be used in conjunction with the Slope Steepness and Landslips Map (Map 6), with more details on the geotechnical properties of materials provided in Chapter 10. These maps are intended for use for regional feasibility studies and should not be used to replace detailed site investigation and geotechnical studies of a site.

Water resources and flooding (Map 8)

This map presents information on the water resources in the District, including both surface and groundwater resources. The map shows the distribution of the principal reservoirs, rivers and canals, and areas of washland, classified as alluvial floodplains prone to flooding. The distribution of the principal aquifers in the District, areas of recharge potential of these aquifers and areas where man-made deposits are directly underlain by the aquifer are also shown. The map also shows the licensed surface and groundwater abstraction sites, with details of each numbered site provided in Appendix 14.3. The location of major faults, derived from Map 2, are shown, as the presence of fractures associated with faulting may result in increased permeabilty and groundwater transmissivity.

Details of the ground and surface waters of the area are given in Chapter 11 of this report. The problem of leachates is discussed further in Chapter 12.

Plate 1 Scarp and dip slope topography in the Coal Measures at Thornton. This is evident in the left middle ground with a dip slope produced by hard sandstone of the 48 Yard Rock, interbedded with relatively soft mudstones and siltstones. Further escarpments in the Elland Flags, near distance, and Millstone Grit sandstones, far distance, are also seen.

6 Geological and geographical background

Introduction

This chapter summarises aspects of the geography and geology of the District. The physical setting is discussed in relationship to the location, topography, geomorphology and history of development. The nature of the bedrock geology, superficial deposits, soils and geological conservation sites are described in turn.

Physical setting

The City of Bradford Metropolitan District is one of the five Districts of West Yorkshire (Figure 1), occurring to the west of the urban conurbation of Leeds, and to the north of the urban areas of Halifax (Calderdale District) and Huddersfield (Kirklees District). It comprises about 370 km^2 with a population in 1991 of about 475 000. Only about one third of the District is built up, but this area contains about 86% of the population. The majority of the population live in the City of Bradford (approx. 300 000 inhabitants), with additional population centres including Keighley, Shipley, Bingley and Ilkley. The population centres are separated by areas of agricultural land, with isolated villages, and areas of undeveloped moorland.

Topography

Topographically, the District comprises a series of escarpments or plateaux, with elevations up to 455 m OD at Round Hill [SD 979 350], and a general decrease in the height of the plateaux toward the east. The escarpments are dissected by the Rivers Aire and Wharfe and a number of smaller rivers, including Bradford Beck and the River Worth. The drainage pattern is shown on Map 8 and discussed further in Chapter 11 of this volume. The valley sides are commonly very steep, in contrast to the flat nature of the valley bottoms and the interfluves. This is particularly apparent on Map 6, which presents contours of slope steepness. The valleys, or dales, of the Rivers Aire and Wharfe form, topographically, the lowest points in the District at about 55 m OD. The main urban centres and transport routes occur within the dales of the District. Within these urban areas the topography has often been altered artificially, with large areas of Made Ground, disturbed ground and excavation.

Geomorphology

Geomorphologically, the area is considered to be part of the upland Pennine peneplain (Richardson, 1976). The peneplain generally slopes eastward, matching the regional dip of bedrock strata to the south-east. However, the peneplain is complicated by valley incisions and a series of step-like features marking breaks in slope. The thick, relatively hard, sandstones of the Coal Measures and Millstone Grit tend to form even, gentle dip slopes in the interfluves, bounded by steep scarp slopes (Plate 1). Intervening mudstones are relatively soft and less resistant to erosion and as a result tend to form slacks, or linear depressions. Where a series of thick sandstones with interbedded mudstones crops out along a valley margin, a step-like topography is common. The regional dip of strata toward the south-east often results in valleys having a marked asymmetry, with steeper north-westerly facing slopes and gentler south-easterly facing slopes, e.g. the Worth Valley between Oxenhope and Keighley, and Bradford Beck between Bradford and Shipley.

The regional slope and dip of strata tends to control the flow direction of the principal rivers toward the east, with

Plate 1 Scarp and dip slope topography in the Coal Measures at Thornton. This is evident in the left middle ground with a dip slope produced by hard sandstone of the 48 Yard Rock, interbedded with relatively soft mudstones and siltstones. Further escarpments in the Elland Flags, near distance, and Millstone Grit sandstones, far distance, are also seen.

the rivers cutting into the old erosion surface. The rivers commonly eroded preferentially along the lines of major faults, as is the case with the Rivers Wharfe and Aire. By the beginning of the last glacial period, many of the main valleys are considered to have developed mature forms, with wide, gently rounded cross-sections (Richardson, 1976).

History of Development

Evidence of Neolithic occupation of the District includes the presence of barrows, stone circles, e.g. The Twelve Apostles on Ilkley Moor [SE 126 451]; and numerous 'cup and ring' stone carvings on Ilkley Moor. The first recorded occupation of the District was by the Romans, who established the garrison fort of *Olicana*, in present day Ilkley. The Domesday Book, of 1086, provides the first written information on late Anglo-Saxon settlements in the District, the names of many surviving to the present (Richardson, 1976). A summary of the medieval evolution of the isolated agricultural villages and the development of small-scale industries is presented by Richardson (1976). The rapid growth of the urban areas of Bradford occurred during the mid-19th Century and can largely be attributed to the exploitation of abundant and varied mineral resources, including coal, ironstone, fireclay, brick clay and sandstone and of the textile industries. Over the past few decades there has been a decline in the main heavy industries, on which the prosperity of the District was based. However, new light manufacturing and service industries have replaced many of the traditional industries. The industrial development of Bradford is summarised by Richardson (1976) and Firth (1990).

Economic growth during the 19th Century was facilitated by the establishment of a good transport network with the rest of the country. During the 1770s the Leeds–Liverpool Canal was constructed along the Aire Valley, connected to the the town of Bradford by the Bradford Canal (Firth, 1983). By the mid-19th Century several railways converged on Bradford. During the latter part of the 20th Century road communications have been improved, notably with the M606 motorway linking Bradford with the M62 motorway, and improvements of the A65 and A650 trunk roads in the Wharfe and Aire Valleys, respectively.

Bedrock geology and structure

The bedrock geology and structure at the surface in the District are presented on Map 2, with Figure 3 (*see* rear of book) being a simplified map of the outcrop pattern. The bedrock is composed entirely of rocks deposited during the Upper Carboniferous, about 315 to 310 million years ago. The south-east of the District, including the main Bradford conurbation and the outlier of Baildon Moor, is underlain by Coal Measures of Langsettian (Westphalian A) age. The District is located at the northern margin of the exposed Yorkshire Coalfield, with the Coal Measures providing the main mineral resources in the District, including coal, ironstone, fireclay, brick clay and sandstone.

The Coal Measures are underlain by the Millstone Grit, of Namurian age, which occurs at outcrop over most of the north and west of the District. The Millstone Grit generally lacks the workable coal, fireclay and ironstone of the Coal Measures, but some of the sandstones have been worked extensively for building stone.

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 a basis for understanding the geological structure. Using the proven vertical succession of geological units and their inclination, it is possible to calculate where these units crop out at rockhead.

Depositional environments

During the Upper Carboniferous, northern England lay within a large, actively subsiding basin. Extensive delta systems, fed with sediments eroded from the surrounding land surfaces to the north, built out into the basin. Coarser grained sediments were deposited where delta systems were active and eventually became lithified as sandstones, whereas fine-grained background sedimentation, usually muds, occurred in more quiescent areas and became lithified as mudstones.

Variations in sea-level are reflected in the Millstone Grit 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"). The marine bands are generally a few centimetres thick, but may attain thicknesses of 2–3 m. They can be recognised across large areas, and as each marine incursion generally contains distinctive and diagnostic marine faunal assemblages, marine bands represent important marker horizons. About 50 marine bands are recognised in the Millstone Grit of the Pennines.

The marine bands commonly pass up through mudstones into siltstones and sandstones, representing a transition from sedimentation in the delta slope to within distributary channels on the delta top. During late Namurian times, the top of each cycle, when sea-level is at its lowest, was often 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, with the deposits of an individual cycle known as a cyclothem. The sequence of development described above is idealised and may be interrupted or modified.

During Westphalian times, the pattern of sedimentation described for the Millstone Grit continued, but with increasing dominance of shallow-water deposits. In the early Langsettian (Westphalian A), deposition was in a shallow water delta/lower delta-plain environment, passing gradationally into upper delta plain conditions in the late Langsettian (Westphalian A) (Guion et al., 1995). Periods when the area was above sea-level and land floras were abundant became more frequent and more prolonged, resulting in complicated patterns of coal seam development. Conversely, marine incursions onto the delta plain became less frequent and less prolonged, resulting in only two Westphalian marine bands being recognised in the sequence present in the District.

The nature of sedimentation in the Millstone Grit is reviewed by Collinson (1988) and in the Coal Measures by Guion et al. (1995) and Chisholm et al. (1990).

Carboniferous: Millstone Grit

The Millstone Grit present in the District comprises about 1830 m thickness of interbedded mudstone, siltstone and sandstone (often referred to as 'grit'), deposited during the Namurian period, approximately 315 million years ago. The Generalised Vertical Section, Figure 4, shows the geological succession in the District including the main sandstones, coals and marine bands. It may be used to estimate

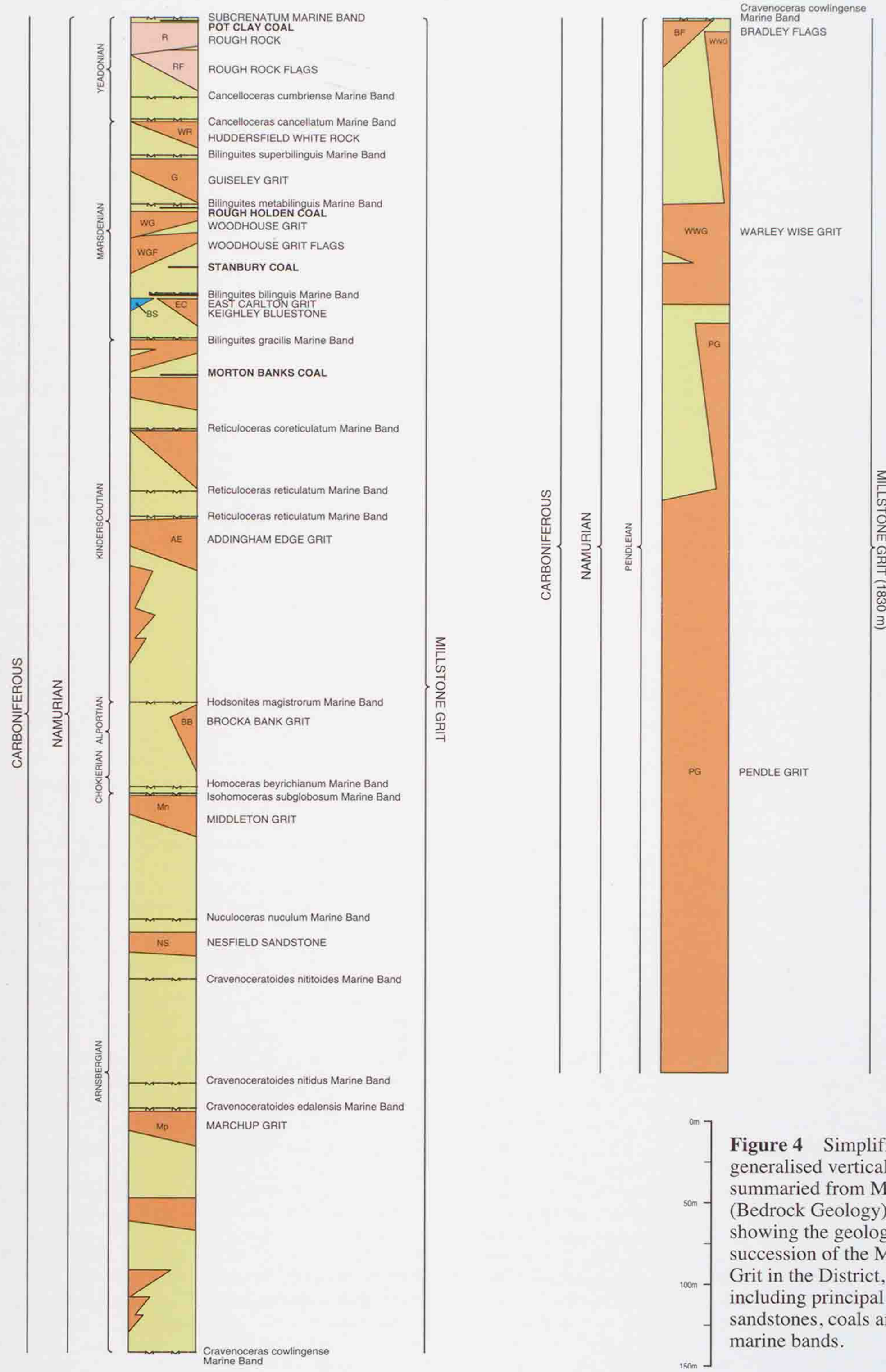


Figure 4 Simplified generalised vertical section, summaried from Map 2 (Bedrock Geology), showing the geological succession of the Millstone Grit in the District, including principal sandstones, coals and marine bands.

Table 3 The principal sandstones of the Millstone Grit, with indication of their thickness and lithology, shown in stratigraphic order with the youngest at the top. The sandstones are grouped into Namurian Stages, with an indication of the approximate thickness of the strata belonging to each Stage.

Stage	Stage Thickness (m)	Principal Sandstones	Sandstone Thickness (m)	Sandstone Lithology
Yeadonian	80	Rough Rock	15-30	Coarse-grained, pebbly, massive or cross-bedded
		Rough Rock Flags	1-21	Fine- to medium-grained, cross-bedded
		Huddersfield White Rock	0-6	Fine-grained, thinly bedded
		Guiseley Grit	10-22	Fine- to coarse-grained
Marsdenian	160	Woodhouse Grit	7-17	Coarse- to very coarse-grained, massive or cross-bedded
		Woodhouse Grit Flags	10-20	Fine- to medium-grained, thinly bedded or cross-bedded
		Keighley Bluestone	0-5	Hard, dark blue-grey siliceous siltstone
		East Carlton Grit	0-23	Fine-grained in west, coarse-grained in east
Kinderscoutian	325	Addingham Edge Grit	20-40	Coarse-grained, pebbly, cross-bedded
Chokierian & Alportian	40	Brocka Bank Grit	0-24	Coarse-grained, thickly bedded
		Middleton Grit	30-45	Fine- to coarse-grained
Arnsbergian	475	Nesfield Sandstone	8-24	Medium-grained, thinly bedded
		Marchup Grit	15-38	Coarse-grained, pebbly
Pendleian	700	Warley Wise Grit	73-210	Coarse-grained, cross-bedded
		Pendle Grit	300-34	Coarse-grained, massive

the succession present beneath an area, but should not be used to supplant a site investigation.

The subdivision of the Namurian System into seven stages is based on goniatites present in marine bands, as reviewed by Ramsbottom et al. (1978) and summarised in Figure 4. These are, in order of decreasing age, Pendleian (E_1) Stage, Arnsbergian (E_2) Stage, Chokierian (H_1) Stage, Alportian (H_2) Stage, Kinderscoutian (R_1) Stage, Marsdenian (R_2) Stage and Yeadonian (G_1) Stage. The area of outcrop of strata are presented in Figure 5. The thickness of strata present for each stage is shown in Table 3.

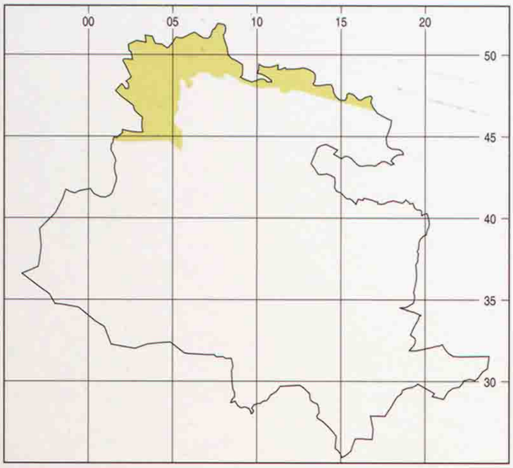
The geological memoir for the Bradford sheet by Stephens et al. (1953) provides a detailed account of the geology of the Millstone Grit with descriptions of localities and regional variations. However, the stratigraphy defined by Stephens et al. (1953) has been superseded by the current geological resurvey of the District. The entire Millstone Grit is considered to be a group, with individual sandstones named. The classification of many of these sandstones is dependent on their position relative to known marine bands. The nomenclature of the principal sandstones, their thickness and lithological properties are summarised in Table 3. Many of the sandstones are coarse-grained ('grits') and form prominent escarpments or 'edges', e.g. Addingham High Moor (Plate 2). It was the former use of these sandstones as Millstones (Plate 2) which gave the name to the entire group. The intervening mudstone- and siltstone-dominated successions are unnamed. The only exception is the Keighley Bluestone, which is a distinctive, unusually hard siliceous siltstone, present to the west of Keighley, which has been used in the past for high quality road aggregate. The Millstone Grit contains relatively few thick coal seams. The age and thickness of those Millstone Grit coals which have been worked are presented in Table 5.

Carboniferous: Coal Measures

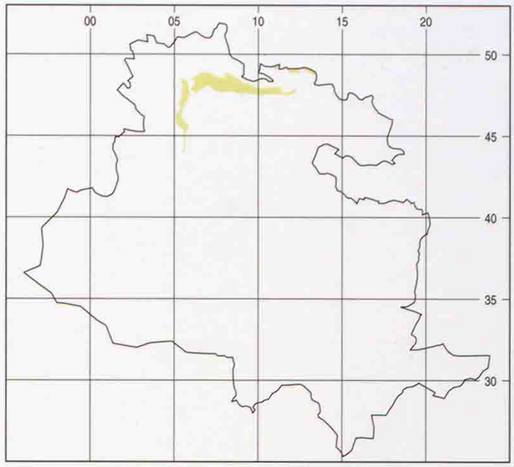
The Coal Measures present in the District consist of about 590 m thickness of interbedded mudstone, siltstone and sandstone, with subordinate coal, seatearth and ironstone, deposited about 310 million years ago. The Generalised Vertical Section, Figure 6, shows the Coal Measures succession in the District including the main sandstones, coals and marine bands.

The geological memoir for the Bradford sheet (Stephens et al., 1953) and Huddersfield sheet (Wray et al., 1930) provide a detailed account of the geology of the Coal Measures, with descriptions of localities and regional variations within the District. However, the stratigraphy defined in these memoirs has been amended by the current geological resurvey.

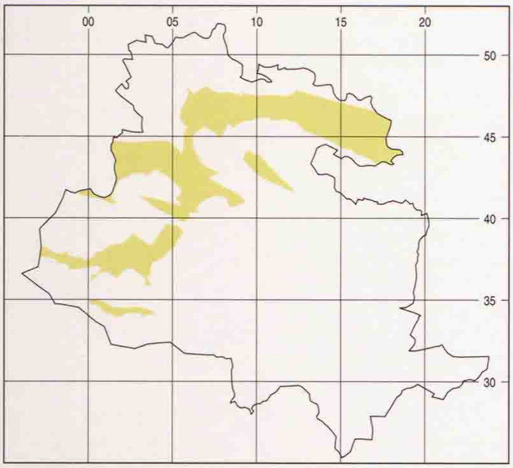
The Coal Measures are divided for convenience into Lower, Middle and Upper divisions, of which only the Lower Coal Measures, of Langsettian (Westphalian A) age (Ramsbottom et al., 1978) are present in the District. The Coal Measures rest conformably upon the Millstone Grit, with the base taken as the base of the Subcrenatum (Pot



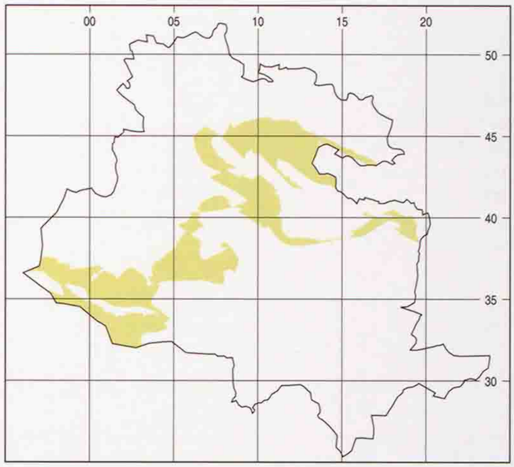
a Rocks of Pendleian (E1) and Arnsbergian (E2) ages



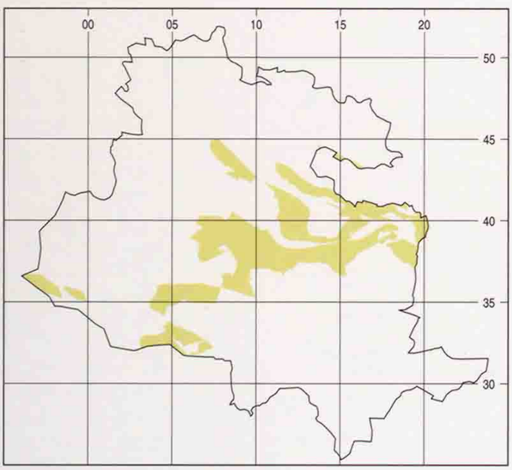
b Rocks of Chokierian (H1) and Alportian (H2) ages



c Rocks of Kinderscoutian (R1) age



d Rocks of Marsdenian (R2) age

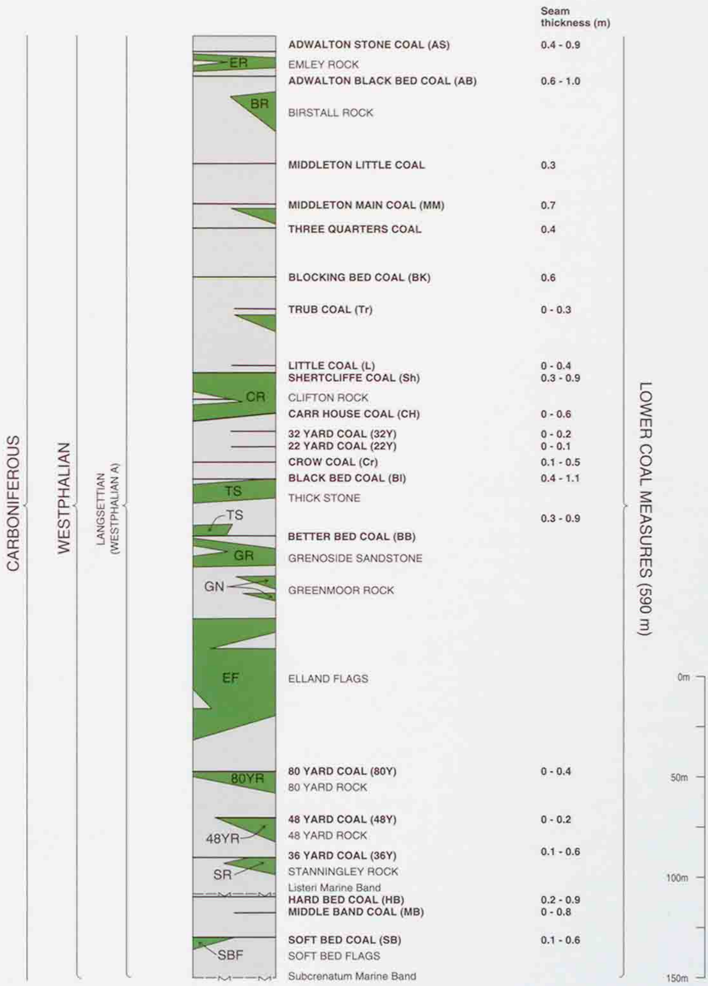


e Rocks of Yeadonian (G1) age

Figure 5 The area of outcrop of Millstone Grit, with subdivision of strata into the Stages of the Namurian System.

Plate 2 View of a Kinderscoutian sandstone crag with cut millstones lying amongst rock fall boulders, at Addingham High Moor [SE 07 47].

Figure 6 Simplified generalised vertical section, summarised from Map 2 (Bedrock Geology), showing the geological succession of the Coal Measures in the District, including principal sandstones, coals and marine bands.



Clay) Marine Band. The sandstones often form positive, mappable, topographic features and are thus distinguished on Map 2 from the mudstones and siltstones, which are shown as Lower Coal Measures (undivided). The nomenclature of Coal Measures sandstones used in this report is shown on Table 4. In contrast to the Millstone Grit sandstones, the sandstones of the Lower Coal Measures are generally fine-grained and are grey when fresh, weathering to yellowish brown.

Mudstone was formerly worked locally for brick clay. Ironstone nodules or layers are common in the mudstone, and in the case of the Black Bed Ironstone were of sufficient thickness and quality to have been worked in the Low Moor area, in the south-east of the District. Seatearths may develop in all lithologies, being referred to as ganister when developed in sandstone or fireclay when formed in mudstone. Fireclay, in particular, has been mined in parts of the District and is still actively worked in a clay pit at Denholme. Commonly, though not always, the seatearth is overlain by a coal seam. Coal seams may be developed over large areas, varying laterally in both thickness and composition, chiefly by variation in the number of dirt partings. With the limited presence of marine bands in this part of the sequence, widespread coal seams provide useful marker horizons. The extensive mining for coal, particularly during the 19th Century and early 20th Century, has provided much information on the identification and correlation of coal seams in the District. The nomenclature of coal seams, with alternative local names and their thickness variations and former use, is shown on Table 5.

Further details of the economic importance of the bedrock geology of the Millstone Grit and Coal Measures is provided in Chapter 7 of this report.

Structural Geology

Most of the main faults in the District probably initiated as pre-Carboniferous structural lines of weakness, which have been repeatedly re-activated during subsequent deformation events. During early Carboniferous times a phase of crustal extension produced a series of horst and graben (Leeder, 1982). During Namurian and Westphalian times the degree of faulting diminished (Leeder, 1982), though some of the major faults may have still been active and influenced sedimentation. This appears to be supported by dramatic thickness variations within the Millstone Grit across the Denholme Clough Fault, in the area of Oxenhope. Guion and Fielding (1988) suggested that during Westphalian A times, sedimentation patterns were influenced by syn-sedimentary faulting, which has been shown near to the Morley–Campsall Fault between Leeds and Wakefield (Giles, 1989).

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. The deformation comprised extensive faulting, with dominant fault trends of NW-SE to W-E, and often subordinate faults with a NE-SW trend (Figure 7). Folding was generally broad and open, with strata generally dipping gently, dominantly toward the south-east, but with significant local variations.

The folding occurs on two scales. Firstly, there are large (km) scale, open folds probably related to regional compression, much obscured by later faulting. Within the District as a whole, the strata have a broadly consistent dip of 2 to 5° toward the south-east. Secondly, there are smaller (10s–100s m) scale, tighter folds, caused by the 'drag' of strata against fault planes during fault movement. An example of such a structure occurs on Skipton Moor, in the north-west of the District. Here, the Bradley Syncline and Bradley Anticline occur parallel with and respectively to the north-west and south-east of the NE-trending Bradley Fault (Figure 8). Dips of up to 50° are common in the vicinity of major faults, such as close to the Denholme Clough Fault.

Faults in the Bradford District display a normal sense of displacement (Figure 8) and were probably developed in an extensional tectonic environment. However, the NW-trending Aire Valley Fault and W-trending Hewenden Fault appear to mark the northward continuation of a major linear structure, the Morley–Campsall Fault, which is thought to have had a history of strike-slip displacement (Giles, 1989).

Faults may occur as a single, discrete plane, or as a zone up to several tens of metres wide containing several fractures, each accommodating some of the displacement. The portrayal of such faults as a single line on the Bedrock Geology map (Map 2) is therefore a generalisation. The position of a fault shown on a map is based on the interpretation of topographic features, surface outcrops, site investigation data and underground mining data but the evidence is rarely sufficient to locate a fault precisely. Only rarely are faults exposed in the District. In an area of thick and extensive superficial deposits, the positioning of

Table 4 The main sandstones of the Coal Measures of the District, showing the range of thickness and lithological description.

Sandstone name	Thickness (m)	Lithological description
Emley Rock	3–5	Fine-grained, thinly bedded
Birstall Rock	0–22	Coarse-grained, pebbly, massive
Clifton Rock (Oakenshaw Rock)	20–30	Fine- to medium-grained, cross-bedded
Thick Stone	7–16	Fine-grained, greenish grey
Grenoside Sandstone	10–16	Very fine- to fine-grained, micaceous, cross-bedded
Greenmoor Rock	0–8	Siltstone to very fine-grained sandstone, greenish grey
Elland Flags (includes Gaisby Rock)	40–75	Very fine- to medium-grained, micaceous, parallel laminated or cross-bedded
80 Yard Rock	0–15	Fine-grained, micaceous
48 Yard Rock	0–15	Fine- to medium-grained, micaceous, thinly to thickly bedded
Stanningley Rock (32 Yard Rock)	0–10	Siltstone to fine-grained sandstone, micaceous, thinly bedded
Soft Bed Flags	0–8	Fine-grained, micaceous, thinly bedded, cross-bedded

Table 5 The main worked coal seams in the District, showing the alternative names, seam thickness and former use.

Stage	Coal seam	Alternative name	Thickness	Former use
Langsettian (Westphalian)	Middleton Main		0.7	
	Blocking	Silkstone	0.6	Household & Engine coal
	Little	Top Beeston	0–0.4	
	Shertcliffe	Whinmoor	0.3–0.9	Engine coal
	Carr House		0–0.6	
	Crow		0.1–0.5	Gas & Household coal
	Black Bed		0.4–1.1	Household, Engine & Gas coal
	Better Bed		0.3–0.9	Coking coal
	36 Yards	Upper Band	0.1–0.5	
	Hard Bed	Halifax Hard Bed	0.2–0.9	Engine coal
	Middle Band		0–0.8	
	Soft Bed	Halifax Soft Bed	0.1–0.6	Coking coal
	Rough Holden	Rivock Edge	0–1.5	
Marsdenian	Stanbury		0–0.3	Engine coal
	Thwaites Brow		0–0.6	

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, variation in the fault inclination would result in an incorrect projected position. Therefore, the position shown on the geological map may be subject to errors of several tens of metres.

Geological faults in this area are of ancient origin and are currently mainly inactive. 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 District and fault reactivation is unlikely to result from any residual subsidence that may still occur.

Drift

About 60% of the District is covered by drift (natural superficial) deposits. These include glacial deposits, such as Till, Hummocky (moundy) Glacial Deposits, Glaciolacustrine Deposits and Glaciofluvial Deposits, and periglacial or post-glacial deposits, such as Head, Peat, Alluvium, Alluvial Fan Deposits, River Terrace Deposits and landslips.

The surface disposition of drift deposits in the District are presented on the Superficial Deposits map (Map 3), with Figure 9 (*see* rear of book) being a simplified map of the outcrop pattern. The limits of the drift deposits have been taken as those defined during the previous geological survey of the District, unless data collected during the current survey has revealed errors in the pre-existing geological maps. The new data may include field observations, such as recent open sections, topographical features and auger holes, or available borehole data.

The drift deposits present across most of the District are less than five metres thick. However, drift-filled channels have been recognised from borehole information as broadly following the modern Aire and Wharfe valleys, and which may attain thicknesses exceeding 50 m (Figure 10). The origin of these glacial channels are discussed below.

Details of Drift Deposits

The nature of the types of drift deposits shown on Map 3 are described separately below, with the relative disposition of the deposits shown on a schematic cross-section (Figure 11).

Till

Till (boulder clay) is the main glacial deposit in the District, forming an extensive, featureless spread, generally less than 5 m in thickness. Price et al. (1984) recognised several different types of Till in Wharfedale and it is probable that these deposits are essentially the same across the District, with variations in the types of boulders found dependent upon local differences in the underlying bedrock. **Lodgement till**, which were plastered beneath a moving glacier, comprises stiff, overconsolidated, blue-grey clay with scattered, subrounded, pebbles and cobbles of Millstone Grit or Coal Measures sandstones and Carboniferous limestones. Drumlins, which are mounds of lodgement till elongate parallel with the direction of ice-flow, have only been recognised in the District along the eastern margin of Rombalds

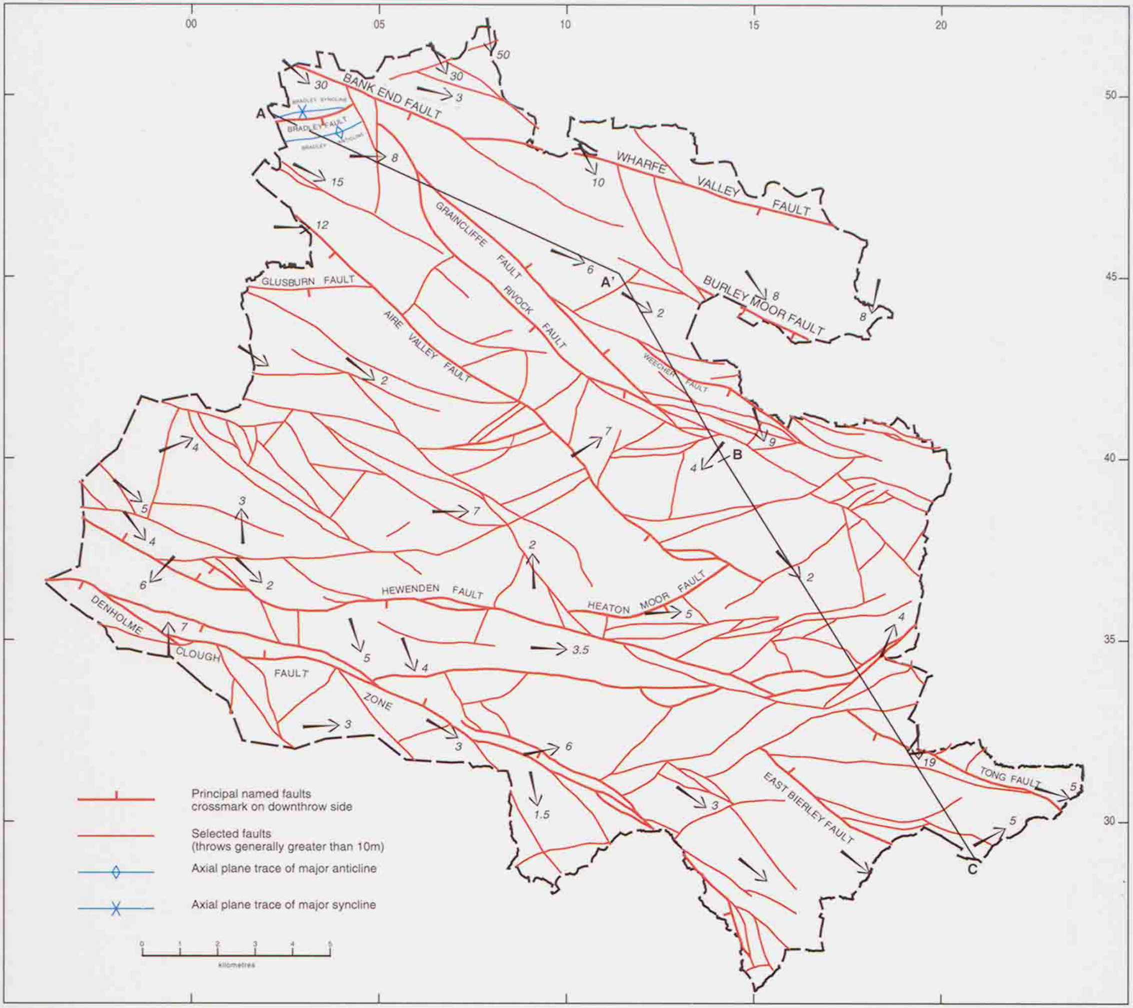


Figure 7 Main structures in the District, including faults, folds and regional dips.

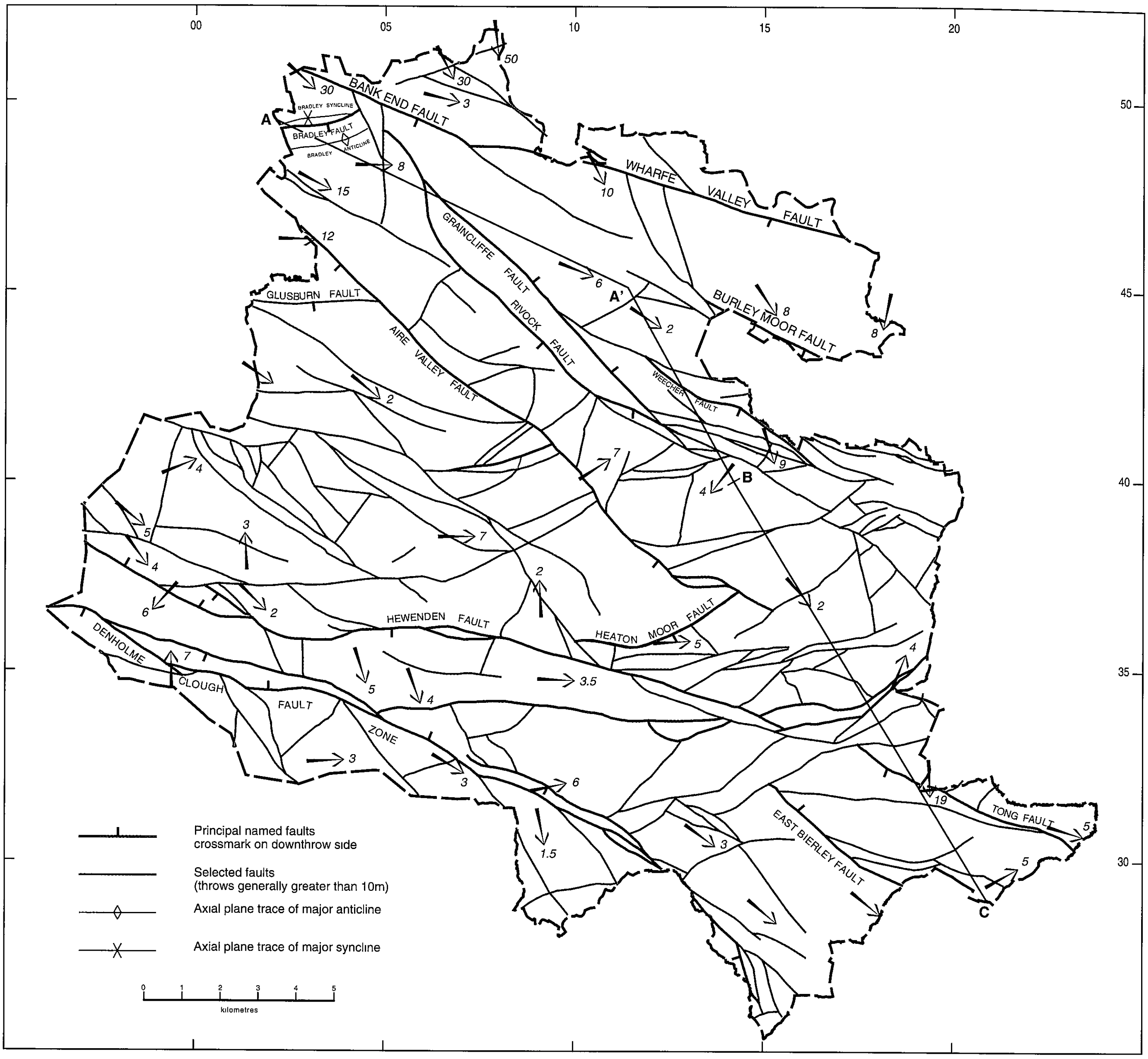


Figure 7 Main structures in the District, including faults, folds and regional dips.

Moor, from Burley-in-Wharfedale to Menston (Stephens et al., 1953). **Flow till**, which formed by the mass movement of glacial debris following release from the glacial ice, commonly comprises brown sandy clay with angular sandstone fragments and may show crude bedding or flow lamination. **Deformation till**, which formed by squeezing or pressing of glacial debris at the base of the glacier, commonly overlies, and grades down into, mudstone bedrock and comprises a firm to very hard clay with abundant mudstone fragments. **Melt-out till**, which formed from the slow release of glacial debris during glacial melting and retreat, is normally consolidated, unsorted sandy, silty boulder clays. Owing to the lack of natural sections and insufficient information recorded in most borehole records, no subdivision of the till has been shown on Map 3.

Hummocky (Moundy) Glacial Deposits

These deposits form circular or elongate mounds of drift, comprising an unsorted mass of boulders and cobbles in a variably sandy or clayey matrix. The Hummocky (Moundy) Glacial Deposits are often difficult to distinguish from Till, with which they are commonly associated. During the resurvey they were distinguished from the featureless sheets of Till by their prominent hummocky topographical features. The majority of these deposits are interpreted as terminal or lateral moraines, which formed at an active ice-front. During the final stage of ice-retreat, the valley glaciers probably retreated in a series of pulses, with the halt-stages marked by terminal moraines. However, hummocky features can also result from the melting of masses of stagnant ice, which may remain within till deposits for some time after the retreat of the main glacier. Hummocky (Moundy) Glacial Deposits occur both in the main valley bottoms, especially the valley of the River Aire, and in upland areas in the vicinity of Wilsden [SE 08 36] and Keighley Moor [SD 98 39]. At Bingley [SE 113 387], these deposits contain many limestone boulders, formerly worked for lime production (see Chapter 7).

Glaciofluvial Deposits

These deposits occur as small, isolated patches from Oakworth Moor [SE 01 40] to Leaventhorpe [SE 12 33],

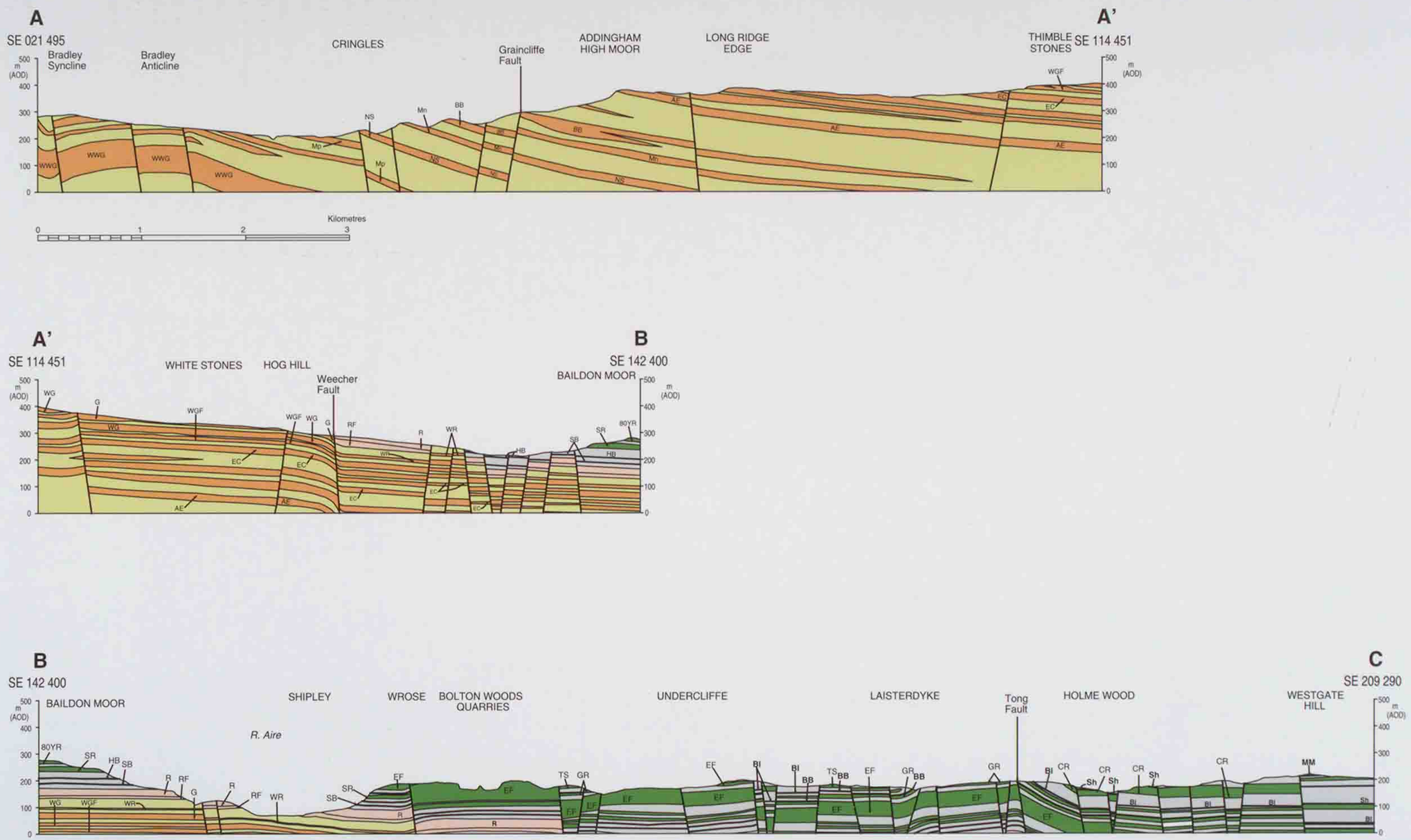


Figure 8 Schematic cross-sections from the NW to SE of the District. See Figure 7 for the location of the section.

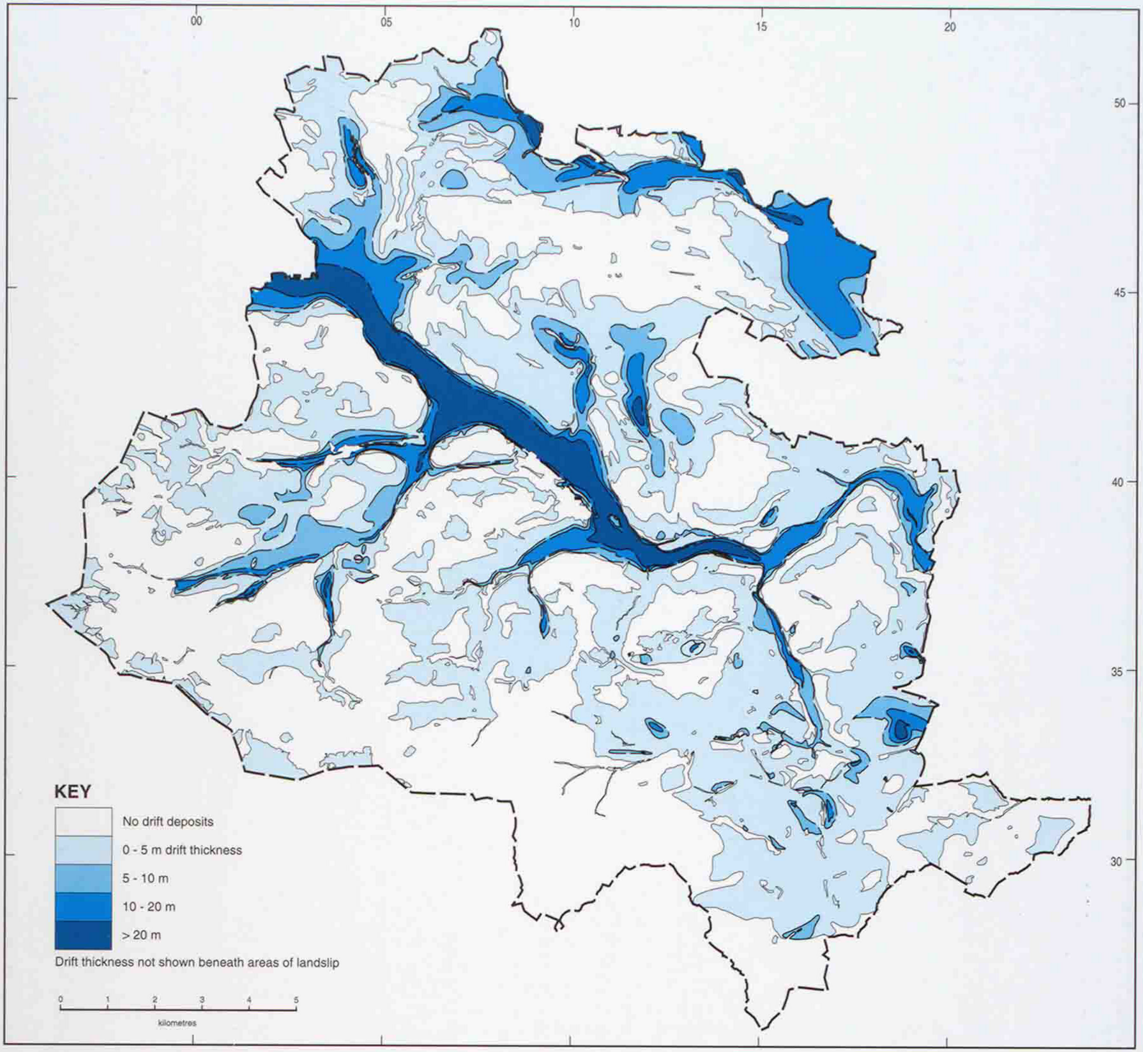


Figure 10 Simplified map, summarised from Map 3 (Superficial Deposits), showing the thickness of drift deposits.

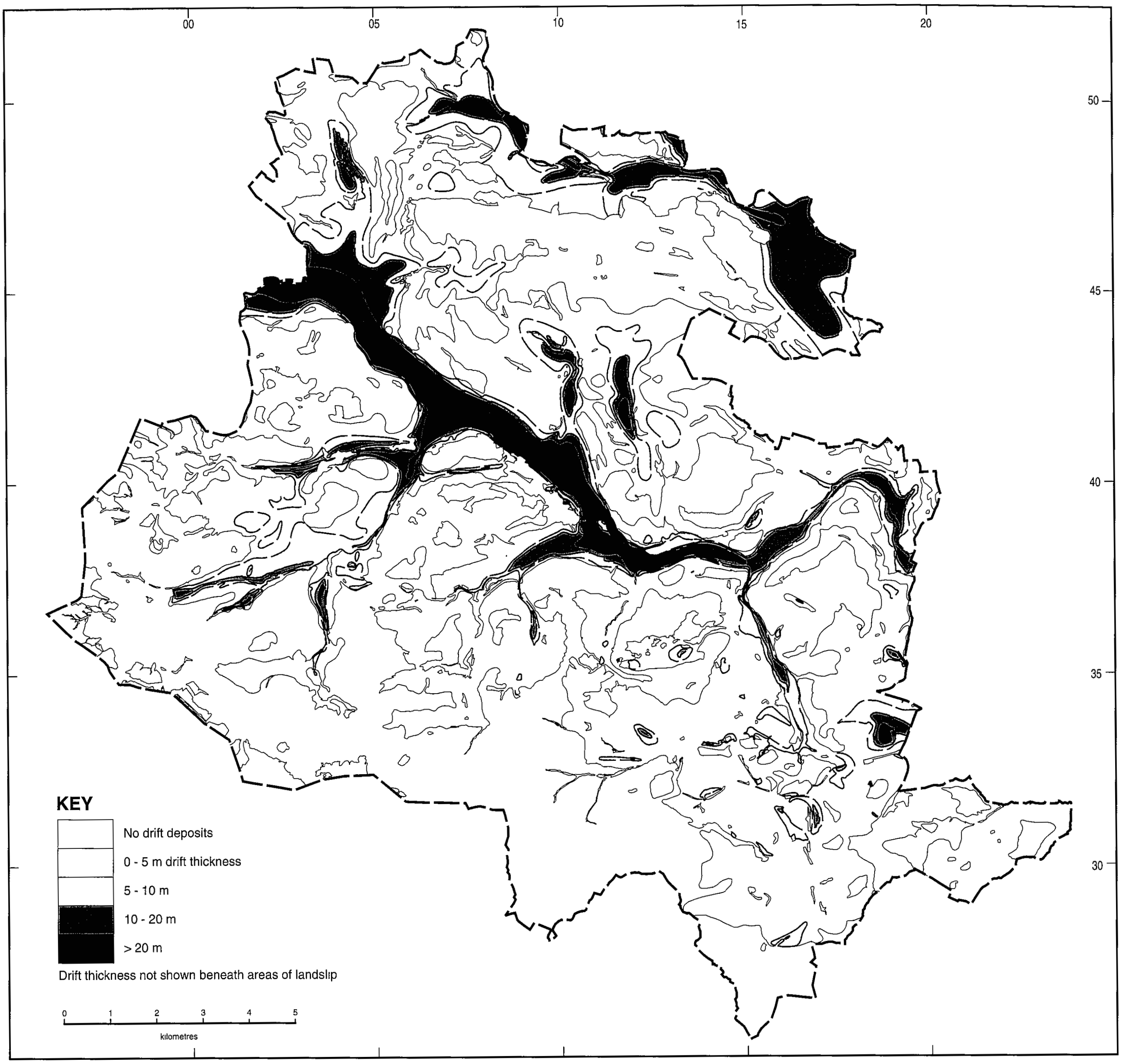


Figure 10 Simplified map, summarised from Map 3 (Superficial Deposits), showing the thickness of drift deposits.

present in both valleys and on plateaux. Further deposits have been proved in borehole records to occur in the buried channels present in the valleys of the Rivers Aire and Wharfe. The deposits comprise bedded sands and gravels, with occasional, thin, laterally impersistent beds of clay. The sand and gravel deposits which form sheets on the plateau between Haworth and Cullingworth [SE 060 354] and [SE 050 366] probably represent outwash deposits (Stephens et al., 1953). Deposits present at the foot of glacial meltwater channels, e.g. at Leaventhorpe, are interpreted by Jowett and Muff (1904) and Stephens et al. (1953) as lake delta deposits, though an origin as subglacial deposits cannot be discounted.

Glaciolacustrine Deposits

These deposits only outcrop at Bingley [SE 10 40], though they have been proved to occur extensively beneath the Alluvium and River Terrace Deposits of the rivers Aire and Wharfe, occupying buried channels. In the Keighley area there is up to 42 m of silty clay and silt with common sand laminae and rarely small stones, interpreted as dropstones released from melting ice masses present on the lake. Late Devensian to early Flandrian lacustrine deposits are proved at Bingley South Bog [SE 115 386] to comprise c.7 m of silty and sandy, calcareous mud (Keen et al., 1988). In Wharfedale, boreholes show the glaciolacustrine deposits to comprise finely laminated clay with grain-thick silty partings or rhythmic graded sequences of fine sand, silt and clay (Price et al., 1984). Glaciolacustrine Deposits are laterally impersistent, interdigitating with Till and Glaciofluvial Deposits. In both Airedale and Wharfedale, they were probably deposited in small lakes dammed by terminal moraines. However, some may have been deposited in kettle holes, small circular depressions formed from the melting of stagnant ice masses within till, e.g. Bingley South Bog (Keen et al., 1988).

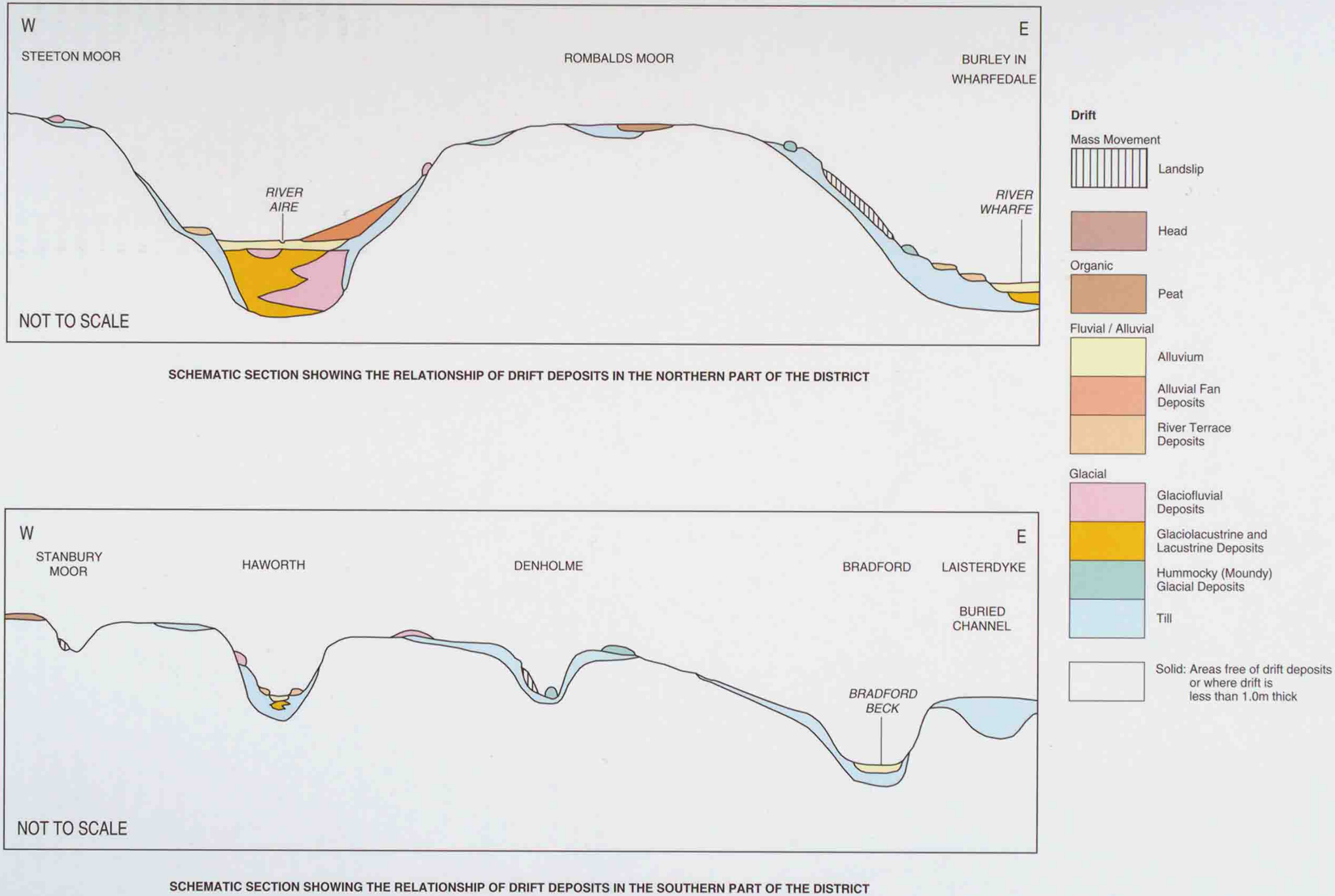


Figure 11 Schematic cross-sections showing the relative disposition of drift deposits.

River Terrace Deposits

In Wharfedale there are three river terraces. The Third and Second River Terraces are present as discontinuous features in the vicinity of Burley-in-Wharfedale, occurring between 3 m and 12 m, above the present floodplain (Price et al., 1984). Although the Third and Second River Terraces are mappable features, the associated deposits are proved by borehole and geophysical data to be very varied and often difficult to distinguish from underlying Till (Price et al., 1984). The First River Terrace of the River Wharfe forms laterally continuous features at Ilkley and Addingham, occurring 3 m to 9 m above the present floodplain. The deposits associated with this lowest terrace include silt and sand with gravel lenses.

In Airedale, only isolated area of First River Terrace have been identified, at Steeton [SE 040 445] and Esholt [SE 19 39]. This terrace is associated with sand and gravel deposits. Locally, in Harden Beck [SE 098 382], two terraces are present, occurring about 2 m and 4 m above the floodplain.

Alluvial Fan Deposits

These deposits have been recognised where the River Worth meets the River Aire, at Keighley. The deposits form a triangular fan, with the apex present in the Worth valley at Ingrow [SE 060 402]. The surface of the deposits falls gently toward the north-east, from 110 m OD at Ingrow to 85 m OD at Aireworth [SE 072 418]. The deposits are proved in boreholes to comprise sand and gravel, up to 17 m thick. A similar, though much smaller, alluvial fan occurs where Holden Beck flows into the River Aire [SE 050 445].

Alluvium

Alluvium is present as wide, laterally persistent spreads in Wharfedale and Airedale, and as small, discontinuous, thin strips in their tributary streams. These deposits are typically heterogeneous. In Wharfedale, the deposits comprise brown silt and fine sand with gravel lenses (Plate 3) and occasional organic clay lenses at the floodplain margins, representing former ox-bow lakes (Price et al., 1984). Similar deposits are have been proved by boreholes in the Aire valley.

Peat

Both lowland and upland Peat are present in the District. Lowland Peat forms small, thin, isolated patches within poorly drained, enclosed hollows, such as Bingley South Bog [SE 115 386] (Keen et al., 1988), and glacial meltwater channels, such as at Pitty Beck [SE 08 34]. At Bingley South Bog, the Peat ranges in thickness up to 3.1 m, resting directly upon Glaciolacustrine Deposits, and are proved to be of Flandrian age (Keen et al., 1988). Wide spreads of Peat also occur beneath Alluvium in the Aire valley, west of Bingley.

Upland Peat forms extensive, thin veneers on the moorland areas in the west of the District, such as Keighley and Oxenhope moors. The deposits are often less than 1 m thick and of insufficient thickness to be mapped during the current resurvey. The extent of the deposits was determined from aerial photographs, used in conjunction with field mapping and auger holes.

Upland Peat accumulates in response to acid soils, low temperatures, poor aeration due to waterlogging and low evaporation rates suppressing the decomposition of dead plant material (Carroll et al., 1979). Upland sandstone escarpments are relatively well-drained and vegetated with heather and the Peat rarely exceeds 1 m in thickness, and often forms only a dark peaty soil. Where mudstone or Till occur at outcrop in moorland areas, the area is often poorly drained, vegetated with sphagnum moss or cotton grass, and Peat deposits may exceed 1 m thickness. Thicknesses of up to 3 m have been recorded at Will's Allotment [SE 021 328]. In many places the soft Peat is being actively eroded to form a network of gullies, or 'haggs', up to 3 m deep (Carroll et al., 1979). Peat was formerly worked in the west of the District, often with detrimental effects to the moorland floral and faunal habitats, e.g. Stake Hill [SE 02 33]. Peat working, heather burning and air pollution may all contribute to increased Peat erosion and reduction in the extent of Peat deposits.

Head

Head deposits are poorly consolidated deposits derived from slow downhill movement, under the influence of gravity, of drift deposits or weathered bedrock. Head may develop in response to solifluction and/or colluvial processes. Solifluction results from the over-saturation of deposits, due to seasonal melting snow and ice, and downslope movement over impermeable frozen ground (permafrost). This process would have occurred in the District during the Devensian glacial period, when Bradford was located at the main ice-front and glacial and periglacial conditions prevailed. Colluvial processes of hill creep and hill wash occurred during the Flandrian and are locally active at present.

Head comprises an unsorted deposit, the composition of which closely reflects those of the upslope source material. The deposits are often difficult to distinguish from weathered bedrock or Till, particularly in borehole records. Head is probably widespread throughout the District, but has been mapped only where it exceeds 1 m thickness and where it is readily distinguishable from either weathered bedrock or Till. The deposits have accumulated in hollows or at the bases of steep slopes, such as below the scarp of the Rough Rock in the Aire valley [SE 103 394]. Here, the deposit comprises angular boulders of locally derived sandstone in a sandy clay matrix.

Landslips

Landslip deposits are a common feature of the District, particularly on the steep slopes of Airedale and Wharfedale and tributary valleys. The extent of landslips are shown on maps 2, 3 and 6, and their nature, processes of formation and relevance to planning and development are discussed fully in Chapter 9.

Summary of Quaternary history

The present day topography is largely the result of glacial processes active during the Pleistocene. The District has probably been affected by glaciation at least three times during the Pleistocene, although evidence for earlier phases has been obliterated by the final, Devensian, phase. During the Devensian glaciation, the land was exposed to periglacial weathering in advance of the ice sheet as it emerged from the Lake District and Southern Scotland. The intense cold caused shattering and weathering of rock due to freeze-thaw processes, and the development of permafrost conditions in the subsoil. Temporary thawing of the ground surface during the short summers resulted in the water-saturation of the products of weathering, which could then flow downhill over the still frozen subsoil to form Head deposits.

The maximum southward advance of the Devensian ice-sheet reached a line approximately crossing the District

Plate 3 Alluvium of the River Wharfe, east of Ilkley [SE 145 480] exposed in a 2 m high bank. The section comprises silty sand above pebbles and gravel.

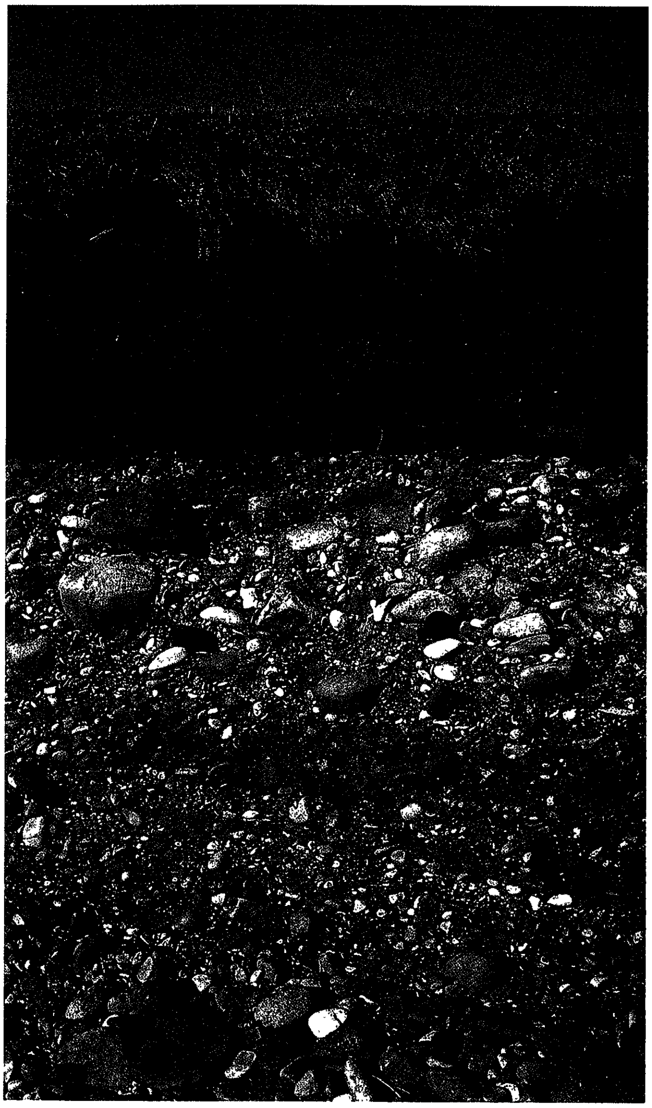


Plate 3 Alluvium of the River Wharfe, east of Ilkley [SE 145 480] exposed in a 2 m high bank. The section comprises silty sand above pebbles and gravel.

from the northern margin of Keighley Moor [SD 98 42] to Low Moor [SE 16 28]. During the maximum advance of the ice, glaciers would have covered both valleys and upland areas. However, for much of the time, at the southern margin of the ice-sheet, glaciers would have only occupied areas of low-ground, such as the Aire and Wharfe valleys. Dramatic fluctuations in temperature, as identified from studies of the flora and fauna present in peat at Bingley Bog [SE 115 386] (Keen et al., 1988), would have caused the valley glaciers to advance and retreat several times during the late Devensian.

The valleys of the modern Rivers Wharfe and Aire broadly coincide with buried, drift-filled channels, locally in excess of 50 m deep. These channels are obscured by a cover of Alluvium, but are proved from borehole data to be filled with a complex interdigitation of Glaciofluvial sand and gravel, Glaciolacustrine silt and clay and Till, occupying a channel with a U-shaped cross-section and an elliptical longitudinal profile (Figure 11). Such channel profiles are unlikely to be produced by fluvial processes from meltwaters derived from a waning ice-sheet. More probably, the channels were formed by glacial scouring and were subsequently infilled with outwash material from the glacier and by sediments deposited in temporary lakes, formed by terminal moraines, during ice-retreat. Alternatively, such channel geometries can develop in response to subglacial erosion by meltwater. The meltwater present at the base of the glacier would be under high hydrostatic pressure and capable of very rapid erosion of laterally impersistent tunnels.

In addition to the large buried channels occupying the main valley bottoms, there are a series of smaller late-glacial, meltwater channels present in the valley sides and upland areas. These have been recognized by Jowett and Muff (1904) and Stephens et al. (1953) throughout the study area, though especially in an arc from west of Keighley to Bradford and Shipley. These features, commonly termed 'glacial overflow channels', typically have a broad E-W to SE-NW trend, approximately parallel to the Devensian ice-front. The channels usually have steep sides and flat bottoms, locally bifurcate and commonly start and end abruptly (Plate 4). Most meltwater channels have been abandoned and are dry or contain only small 'misfit' streams, incapable of eroding such large valleys. Jowett and Muff (1904) and Stephens et al. (1953) considered that the channels represented overspills from glacier-dammed lakes. Alternatively, as for the buried channels of Airedale and Wharfedale, these channels may have developed due to erosion by subglacial meltwater.

Following the Devensian glaciation, the modern drainage pattern became established, with alluvial deposition within the broad valleys of Airedale and Wharfedale, and associated tributary streams. In Wharfedale three terraces and their associated surface deposits have been recognised (Price et al., 1984), in contrast to Airedale, which has only a single river terrace (Stephens et al., 1953). The terraces represent fluvial erosion surfaces which have become isolated on valley sides due to repeated entrenchment of the river systems during the Flandrian. Alluvium represents the alluvial deposits of the current floodplain level. In abandoned meltwater channels, thin deposits of lowland Peat accumulated, whilst more extensive, though thin, upland Peat deposits accumulated on the moors in the west of the District. Landslips are a common feature of the District, occurring in both bedrock and drift deposits. Some landslips may have been initiated during the late stages of the Devensian glaciation, though many are Flandrian in age with some landslips still active.

Artificial (Man-Made) Ground

Introduction

The long history of industrial development in the District has left an extensive legacy of human modification of the natural environment. The deposits associated with these modifications may represent potential hazards, either through unstable ground conditions, generation of toxic leachates or through formation of toxic or explosive gases. This section describes the nature of these deposits and the constraints they impose on planning and development.

The man-made deposits shown on Maps 3 and 5, and summarised on Figure 9, represent those that were identifiable at the date of survey. They were delineated by recognition in the field and by examination of documentary sources, in particular topographical maps, aerial photographs and site investigation data. Only the more obvious man-made deposits can be mapped by these methods and the boundaries shown may be imprecise. Only deposits known to be broadly in excess of 1.5 m thickness are shown.

Plate 4 View of a bifurcating meltwater channel near Newsholme Dean [SE 002 410].

Hazards associated with man-made deposits

Man-made deposits represent a potential hazard in three main ways:

- The often uncompacted or poorly compacted nature of man-made deposits can give rise to unstable foundation conditions. In places the deposits may be very weak or cavernous and cause excessive and uneven settlement. Organic material within the man-made deposits may rot, causing cavitation and settlement below surface structures. When spoil is dumped on a slope, the buried soil/organic layer may be weak and therefore might form a potential failure surface. Poorly managed groundwater flow can produce catastrophic failure of poorly compacted embankments and spoil heaps. The importance of man-made deposits on engineering ground conditions is discussed further in Chapter 10.

- Toxic residues, either as a primary component of the man-made deposit, or generated secondarily by chemical or biological reactions, can migrate both within the deposit and into adjacent permeable strata. The problems associated with leachates are discussed further in Chapter 12.

- Toxic or explosive gases, particularly methane and carbon dioxide, can be generated within waste tips, landfill sites and in disused mine workings. Such gases can sometimes migrate through adjacent permeable strata and accumulate within buildings or excavations, either nearby or some distance away. The problems with landfill and mine gases are discussed further in Chapter 12.

Classification of artificial (man-made) ground

The standard BGS nomenclature for artificial ground (McMillan and Powell, 1993), as summarised on Table 6, is used in this study. Table 6 also shows other commonly used classifications based on the waste composition (Department of the Environment, 1993; Anon, 1993). The morphology of the main types of artificial ground observed in the District is shown on Figure 12.

Landscaped Ground is not mapped during the current survey. This comprises areas where the original surface has been extensively remodelled, but where it is impractical or impossible to delineate areas of cut or made ground. This category is associated with constructional developments such as housing estates or golf courses. It should be assumed that most areas of urban development are associated with Landscaped Ground.

The database showing the main identified landfill sites should be used in conjunction with Map 3. The database showing the main areas of Worked Ground associated with sandstone quarrying should be used in conjunction with Map 4. Details on the information provided by both databases are provided in Appendix 14.6.

Made Ground

Made Ground represents areas where the ground is known to be deposited by man on the natural ground surface (Figure 12). The main categories are the following:

- Civil engineering works, such as road and railway embankments and reservoir dams

- Spoil from mineral extraction industries, such as colliery and quarry spoil

- Building and demolition rubble (brick/stone/mortar etc.)

- Waste from heavy industries, such as foundry sand and slag from ironworks, ashes and cinders from textile mill boilers

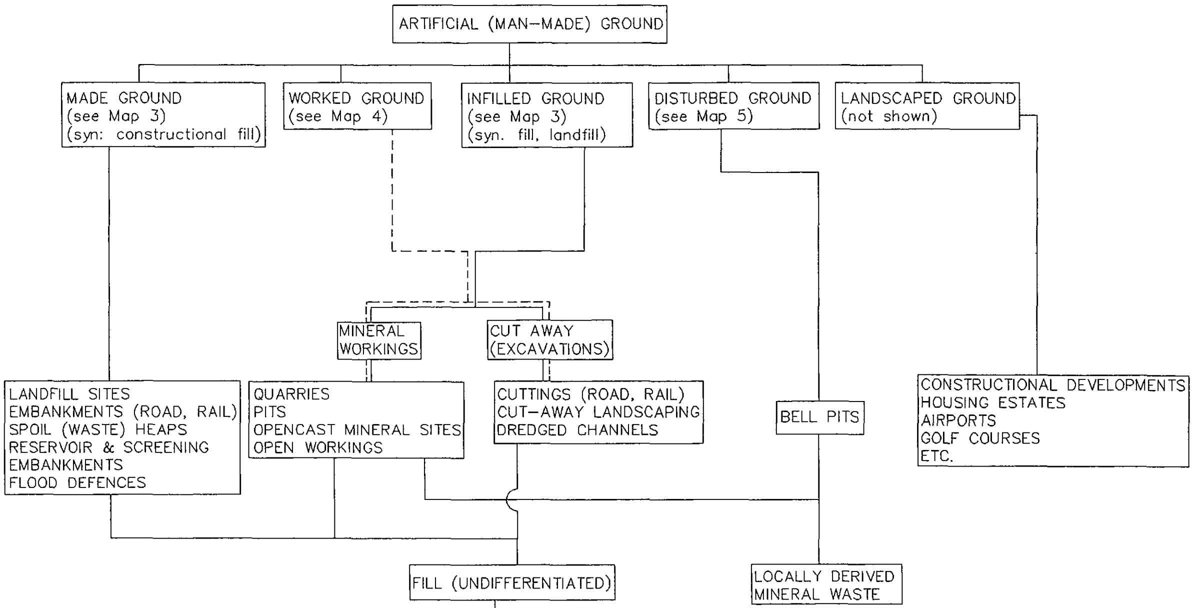
- Domestic and other waste in raised landfill sites

The most extensive areas of Made Ground, shown on Map 3 and summarised on Figure 9, are in the main urban centres of Bradford, Shipley, Bingley and Keighley.

In the urban areas the topographic features associated with specific areas of Made Ground, especially colliery spoil, have been smoothed over prior to development. Construction has often taken place on the compacted rubble and deposits left by previous uses. In such areas, the

Plate 4 View of a bifurcating meltwater channel near Newsholme Dean [SE 002 410].

Table 6 Categories of artificial (man-made) ground.



DoE DETAILED CLASSIFICATION OF WASTE CODE *

A INORGANIC ACIDS
B ORGANIC ACIDS AND RELATED COMPOUNDS
C ALKALIS
D TOXIC METAL COMPOUNDS
E NON–TOXIC METAL
F METAL (ELEMENTAL)
G METAL OXIDES
H INORGANIC COMPOUNDS
J OTHER INORGANIC MATERIALS
K ORGANIC COMPOUNDS
L POLYMERIC MATERIALS AND PRECURSORS
M FUEL, OIL, GREASE
N FINE CHEMICALS AND BIOCIDES
P MISCELLANEOUS CHEMICAL WASTE
Q FILTER MATERIALS, TREATMENT SLUDGE AND CONTAMINATED RUBBISH
R INTERCEPTOR WASTES, TAR, PAINT, DYES, PIGMENT
S MISCELLANEOUS WASTE
T ANIMAL AND FOOD WASTES
U CLINICAL WASTE

* for further subdivisions and listings see DoE Waste Management Paper No. 2/3, 1993

EUROPEAN WASTE CATALOGUE (EWC) CLASSIFICATION 1993 +

1 Mining, quarrying and exploration wastes
2 Waste from agricultural, horticultural, hunting fishing & aquaculture primary production, food preparation & processing
3 Wastes from wood processing & the prodution of paper, cardboard, pulp, panels & furniture
4 Wastes from the leather & textile industries
5 Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal
6 Wastes from inorganic chemical processes
7 Wastes from organic chemical processes
8 Wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes & vitreous enamels), adhesive, sealants & printing inks
9 Wastes from the photographic industry
10 Inorganic wastes from thermal processes
11 Inorganic waste with metals from metal treatment and the coating of metals; non–ferrous hydro–metallurgy
12 Wastes from shaping and suface treatment of metals and plastics
13 Oil wastes (except edible oils)
14 Wastes from organic substances employed as solvents
15 Packaging; absorbents; wiring, cloths, filter materials & protective clothing not otherwise specified
16 Waste not otherwise specified in the catalogue
17 Construction and demolition waste including road construction
18 Wastes from human or animal health care and/or related research (excluding kitchen or restaurant wastes which do not arise from immediate health care)
19 Wastes from waste treatment facilities, off–site waste water treatment plants and the water industry
20 Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions

+ for further subdivisions and catagories see European Waste Catalogue

LIST OF COMMONLY USED TERMS FOR WASTE/FILL IN THE UK

AGGREGATE	1
ASBESTOS WASTE	10,17
ASH	10
BALLAST	1
BLAST–FURNACE SLAG	10
BRICK	17
BUILDING RUBBLE	17
CARDBOARD	15
CERAMIC WASTE	10
CHEMICAL WASTE (undifferentiated)	6,7,8,9,20
CHINA CLAY WASTE	1
CLAY (BRICK/TILE) WASTE	1
CLINKER	10
COAL SHALE	1
COLLIERY WASTE (SPOIL)/MINE STONE	1
DOMESTIC/GARDEN REFUSE	20
EFFLUENT	19
FOUNDRY SAND	10
FOUNDRY SLAG	10
FURNACE ASH	10
GARDEN WASTE	20
HERBICIDE	7,20
INDUSTRIAL WASTE (undifferentiated)	many categories
MINE DUMPS (TAILINGS)	1
MINERAL WASTE (undifferentiated)	1
OIL SHALE WASTE	1
ORGANIC WASTE (undifferentiated)	2–4,7,15,17,19,20
PAPER	20
PEAT	10
PESTICIDE	7,20
PLASTERBOARD	17
PULVERISED FUEL ASH	10
QUARRY WASTE	1
RADIOACTIVE WASTE	16
ROCK WASTE	1
SEWAGE SLUDGE	19
SHALE WASTE	1
SLATE WASTE	1
SOIL	17,20
SPOIL	1
TOXIC WASTE (undifferentiated)	many categories
WOOD	3,17,20
ETC...	

(numbers refer to probable ECW classification)

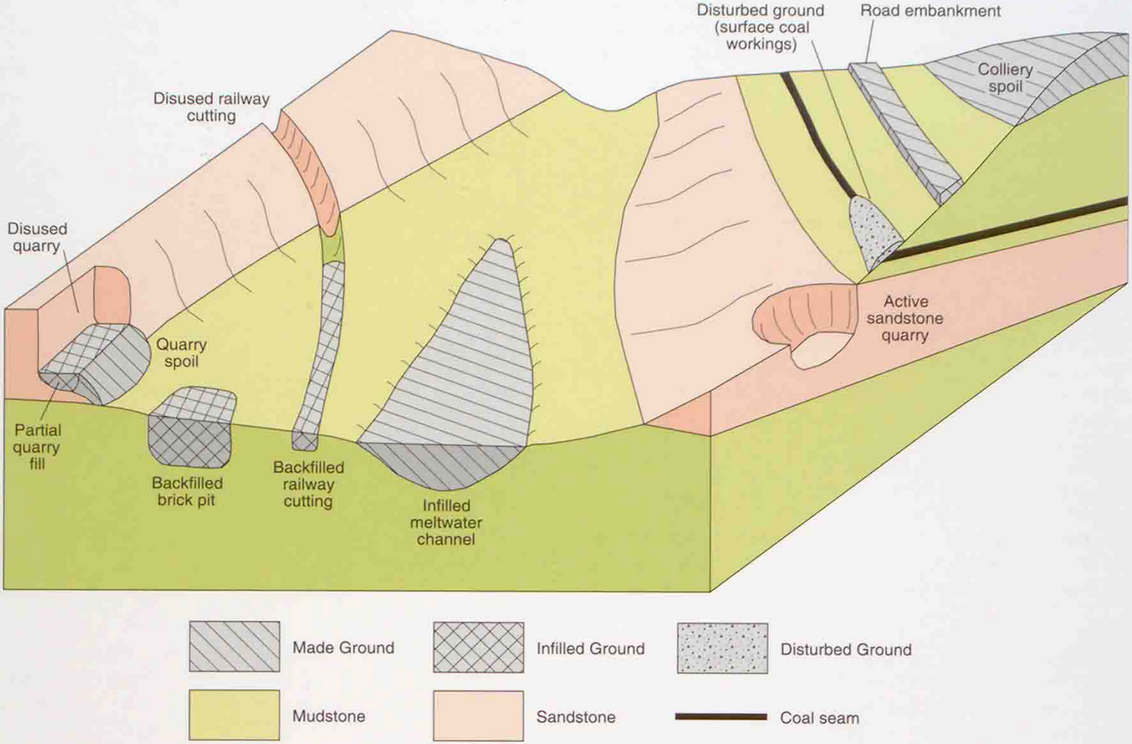


Figure 12 Schematic block diagram showing the types of man-made deposits described in the report.

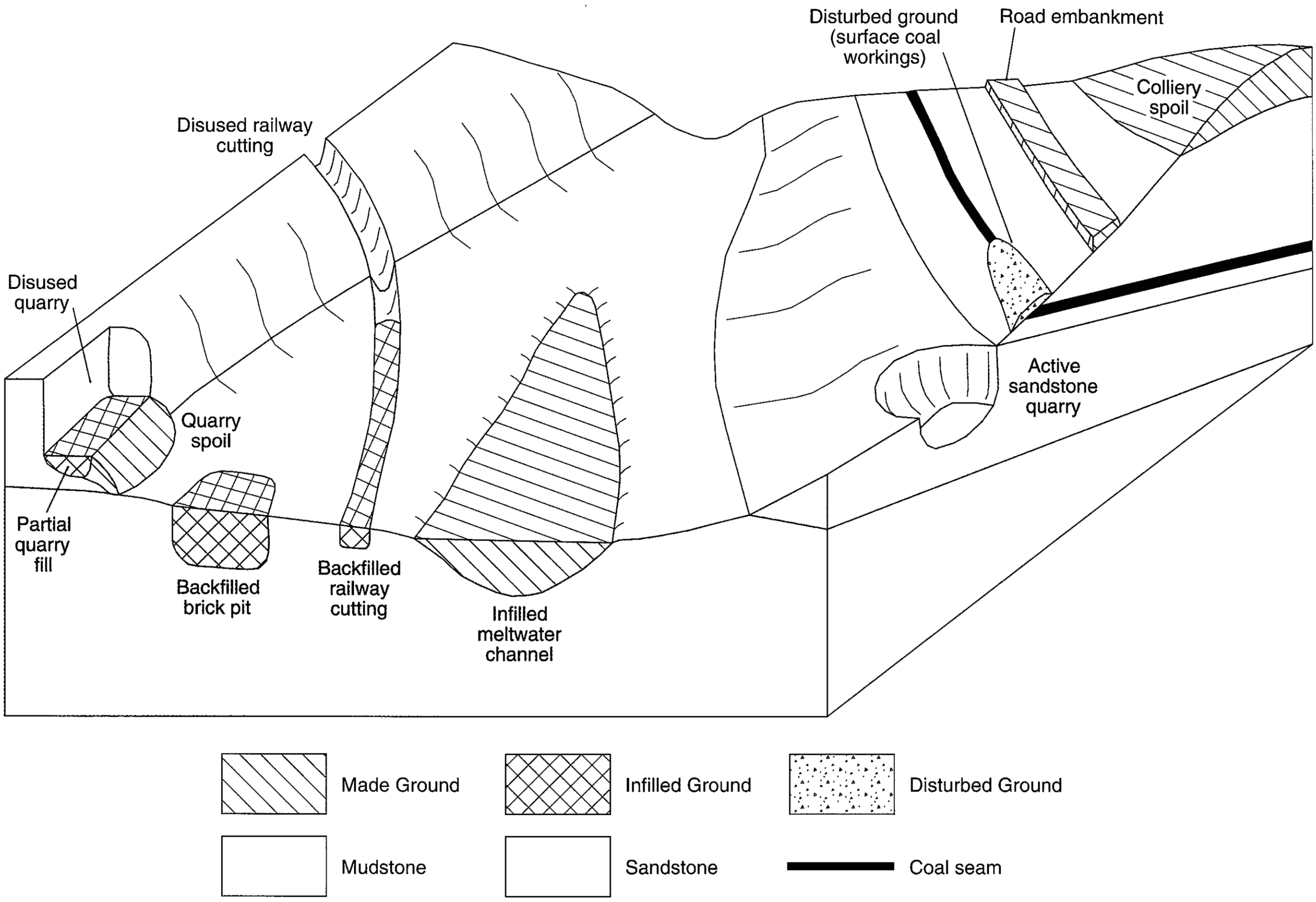


Figure 12 Schematic block diagram showing the types of man-made deposits described in the report.

extent of Made Ground is based largely on site investigation data.

No attempt has been made to subdivide the Made Ground deposits on the basis of their composition. Made Ground is heterogeneous and can rapidly vary in composition, both laterally and vertically. In order to determine the nature of fill material it is necessary for an appropriate site investigation to be carried out. However, in order to provide an indication of the possible bulk composition of Made Ground, Map 3 indicates current and former land-uses associated with some of the main areas of artificial deposits. The association of land-use and Made Ground deposit is discussed fully, below. Similarly, the thickness of Made Ground has not been presented, as such deposits may vary in thickness, dramatically, and often unpredictably, across a site. Borehole records and trial pits can provide site specific information on the nature and thickness of Made Ground, but may lead to erroneous assumptions if used to predict across the deposit as a whole.

Infilled Ground

The combined worked and made ground category, referred to here as infilled ground, comprises areas where the natural ground surface has been removed and the void partly or wholly backfilled with man-made deposits. Mineral excavations and disused railway cuttings have frequently been used for the disposal of waste materials. Quarrying operations in the District have largely been for sandstone, brick clay and fireclay. The waste material from these operations, in particular sandstone quarrying, were often tipped adjacent to the quarries to form spoil mounds of Made Ground. Occasionally, quarries would be partly filled with spoil after the cessation of mineral extraction. However, in most cases quarrying operations produced voids suitable for infilling with imported waste. The common types of fill include excavation waste, construction and demolition waste, domestic refuse and industrial waste. The problems associated with the heterogeneity of these deposits are the same as those discussed for Made Ground.

Where quarries and pits have been restored and either landscaped or built on, there is often no surface indication of the extent of the backfilled void. In such cases, the location of these sites is taken from archival sources, in particular old topographic and geological maps.

Worked Ground

Worked Ground includes areas where material is known to have been removed, for example in unfilled quarries and pits, excavations for roads and railways and general landscaping. Excavations made during the extraction of mineral resources, such as sandstone, fireclay and brick-clay are shown on Map 4. This category includes quarries and pits which were active at the time of survey or were disused but not infilled. A list of active mineral operations in the District is provided in Appendix 14.2. Details on unfilled sandstone quarries are presented in the Sandstone Quarries Database (see Appendix 14.6).

Many former quarries are now wholly or partly backfilled, and those that remain open are, generally, away from urban centres and in more inaccessible locations. Open quarries can pose potential safety hazards to the public, particularly if they are water-filled or have unprotected vertical faces. Quarries may also be a potential resource, providing valuable exposures of geological features, becoming sites of biological importance, offering recreational facilities (climbing) or, if properly managed on abandonment, adding to the scenic value of an area.

Disturbed Ground

These are areas of ill-defined, surface mineral workings in which shallow excavations, subsidence induced by near surface mineral workings and Made Ground are complexly associated with each other. The areas of artificial deposits generally represent small mounds of spoil from the mining operation. The approximate extents of Disturbed Ground are shown on Map 5. This category includes areas of bell pits and shallow mine workings, such as at Baildon Moor [SE 14 40], and Rough Holden [SE 07 45]. Mining methods and the problems associated with poorly constrained areas of near-surface mining are discussed in Chapter 8. This category also includes a feature referred to as 'brickfields' on early editions of Ordnance Survey topographical maps. These are areas where the weathered clay sub-soil was removed for brickmaking. All have subsequently been built over and no records exist to indicate the depth of these workings and whether they were backfilled or levelled. Examples of brickfields are present in the City of Bradford and include sites at Eastbrook [SE 171 328].

Land-use and composition of man-made deposits

The heterogeneity of man-made deposits makes the classification of such deposits on the basis of composition particularly difficult and hazardous. Because of this, no attempt has been made during this project to distinguish between deposits of different composition. However, there is benefit in planners and developers having an indication of the broad make-up of man-made deposits so that they are aware of the risks of difficult engineering ground conditions and the presence of toxic residues and explosive gases, and can ensure that site investigations are designed to assess these problems.

Where material has been added to the environment with a consequential degradation of the land, with respect to a particular current or future use, this process may be regarded to be contaminative. Past industrial activity in the District has left a legacy of land which has been affected by the addition of natural and artificial materials, which may be considered to be contaminants. However, the delineation of contaminated land is difficult, partly because there is little consensus what constitutes contaminated land and also the concern that identification of such areas may affect property values.

An indication of the composition of man-made deposits and the potential for the presence of contaminated land can be provided by studies of current and former land-use. For this project, four phases of Ordnance Survey 1:10 560- and 1:10 000-scale topographical maps, three phases of BGS geological maps, at the same scale, and town maps provided by the local authority, have been used to compile land-use data. A list of topographical and geological maps used in this study is provided in Appendix 14.4.

The land-use information is presented on Map 3. However, the map is not intended to provide a comprehensive distribution of current and former land-use. Land-use information is only displayed when associated with significant areas and thicknesses of artificial deposits. It should be noted that contamination can arise in areas where little, or no, artificial deposits are present. A Contaminated Land Research Report (RPS Consultants, 1994) provides a list of data sources which should be consulted to ascertain comprehensive information on former industrial sites. It is advisable that such documentary research should be carried out as part of any site investigation.

Although land-use information may give an indication of the potential for contamination, it is important to note that the designation of a site to a previous, potentially contaminative land-use, does not, necessarily, imply that the area is contaminated. Furthermore, even if the former land-use did lead to contamination, it is possible that measures have been taken to decontaminate the site.

The main categories, discussed in turn below, have been chosen as they represent common forms of land-use in the District, and may influence ground conditions or result in contamination.

Landfill Sites

The nature of sites used for landfill are extremely variable, they include the following, with examples of typical sites:

- landfill on natural ground (e.g. Odsal [SE 165 297]),
- former quarries (e.g. Egypt Quarry [SE 090 339], Plate 5),
- infilled reservoirs (e.g. Brown Royd [SE 145 333]),
- infilled railway cuttings (e.g. Tyersal [SE 193 328]),
- topographical depressions (e.g. Sugden End [SE 050 374]).

Landfill sites may contain a wide variety of components, including some, or all of the following: paper, cardboard, glass, plastics, metals, wood, kitchen waste, garden waste, textiles, paints, inks, adhesives and resins, solvents, detergents, batteries, construction debris, topsoil, etc. Contaminants may include a wide range of heavy metals, sulphates, sulphides, acids, alkalis, hydrocarbons, general organics, phenols, dioxins and PCBs. This list is not exhaustive.

Historically, little control was applied to the siting of landfills. For areas of backfill pre-dating the introduction of The Control of Pollution Act in 1974, there is little or no indication of the nature of the fill material. They tended to be located, for convenience and economy of disposal, in the nearest available space or void, or where infilling was required. The sites would often be rapidly filled, covered and forgotten. This uncontrolled disposal included a wide range of active and inert waste materials from domestic and industrial sources.

For those sites known to have been filled before the introduction of the Clean Air Act in 1965, it is often the case that domestic wastes have a high component of ash and cinders, with much of the biodegradable material being either burnt or composted. However, the presence of remaining biodegradable material in such sites cannot be discounted. These sites 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 hazardous gases, such as methane and carbon dioxide, and leachates. An appreciation of the geological environment of the site is important in assessing the risk posed by these materials, since both gases and leachates are capable of migration for considerable distances from a site, through permeable sub-surface materials.

Problems associated with current landfills include odours, air-borne litter, dust, noise, vermin, flies, gaseous emissions and leachates. All of these contribute to a deterioration of environmental quality. In particular, gaseous emissions and leachates are a potential long-term problem for more recent landfill sites. After the introduction of the

Plate 5 Former Egypt Quarry [SE 089 339], now largely infilled with domestic refuse with a system of pipes are used to vent methane from the site.

Plate 5 Former Egypt Quarry [SE 089 339], now largely infilled with domestic refuse with a system of pipes are used to vent methane from the site.

1965 Clean Air Act, combustible materials which would have previously been incinerated, subsequently were tipped into landfills and, thus, domestic wastes from after the late 1960s may have a high content of biodegradable materials.

Many of the problems associated with landfill sites have been dealt with through the implementation of environmental protection legislation in the mid-1970s. This has contributed to improved landfill design, operation, monitoring and the retrospective fitting of control measures to existing sites. The aim of the operators of present day sites is to minimise the environmental impact and allow the ultimate reclamation of the land.

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.

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 12.

The Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) 17/78, Department of Environment 1986 and Building Research Establishment Information Paper 2/87 provide general guidance on assessment and redevelopment of landfill sites.

Colliery Spoil

Coal mining results in the production of waste rock during the excavation of access tunnels, shafts and from coal washing. During early mining operations the amount of waste produced was comparatively low, because payment was for the tonnage of coal mined and not for waste, and hand working allowed more selective working of coal. The waste was mostly stowed within the mine or dumped on small tips close to the pit head. In the later stages of mining operations in the District, during the early 20th Century, the introduction of greater mechanisation resulted in increased volumes of waste, because of the less selective methods of mining. The waste was usually carried by tramway/railway, conveyor belt or aerial ropeway away from the minehead and tipped on adjacent land. To minimise the distance of transport and the area of land required, tips were high and steep sided, with slopes at the angle of repose of the waste material. Such a tip is still evident as a prominent feature, now reclaimed, at Tong Street [SE 196 306].

Colliery spoil heaps contain coal and carbonaceous material which, if present in high enough proportions may be combustible. Such fires have been recorded in the District. 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 road construction, such as the spoil mound present on Baildon Moor (Plate 6).

Colliery spoil may contain iron sulphides (iron pyrites) which is prone to oxidise and produce sulphate-rich, acidic leachates, which may be harmful to concrete present in foundations or buried services. This oxidation process may also result in expansion and differential heaving of developments constructed upon such deposits.

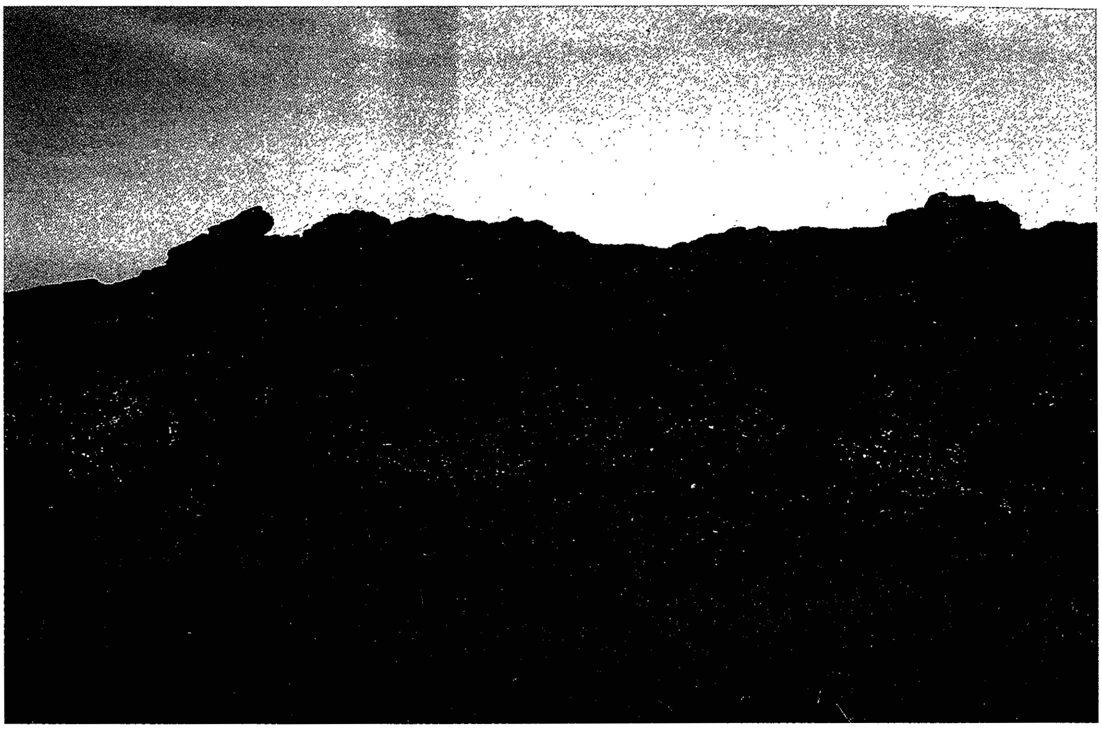
Quarry Spoil

Areas of quarry spoil from sandstone excavations, both at the surface and underground, are a common feature of the District. Waste material derived from both quarrying and the dressing of the stone product, which often occurred at the quarry to minimise transport costs, was generally deposited adjacent to the quarries. Large areas of spoil are recorded adjacent to the former Cliffe Wood Quarry [SE 16 34].

The spoil material is generally inert and is not associated with the formation of hazardous leachates or gases.

Plate 6 Spoil mound of burnt shale at Baildon Moor [SE 1400 4015].

Plate 6 Spoil mound of burnt shale at Baildon Moor [SE 1400 4015].



However, large areas of quarry spoil influence engineering ground conditions (see Chapter 10). Quarry spoil, being inert, may also be useful as bulk fill for road construction schemes.

Gasworks

This includes areas of land used for coal carbonisation, purification, tar storage, dumping of 'spent oxide' and coke storage. Related sites include use for tar refining and asphalt production.

Such sites are often associated with severe contamination of soils and groundwater. Soils are often very acidic with high concentrations of sulphates, phenols, coal tars and other aromatic hydrocarbons, oils, free and complexed cyanides, sulphur and sulphides (Knipe et al., 1993). Heavy metals may include chromium, copper, lead, nickel and zinc and other hazardous substances which may be found at former gasworks include asbestos, benzene, toluene and xylene.

The Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) 18/79 provides general guidance on assessment and redevelopment of gasworks sites.

Railway Land

Includes depots, carriage works and other engineering and storage activities, where ashes, cinder and other fill materials have been used to raise or level the ground. Contaminants include sulphates, heavy metals, oils, solvents and paints, asbestos, PCBs and the fill may be susceptible to spontaneous combustion due to the common presence of timbers and coal debris.

Sewage Works

Sewage works include sewage farms in which sewage was stored, but not treated, and large-scale sewage treatment plants. Sewage farms were used during 18th and early 19th Century as an alternative to the direct pumping of effluents into the river system. The raw sewage would have been spread, untreated, over neighbouring fields and some effluent would have percolated into the groundwater beneath the sewage farms. Embankments associated with a sewage farm at Deep Lane [SE130 326] are still evident.

Waste from sewage treatment plants can include waste from hazardous waste incineration, from chemical treatment of industrial wastes, from aerobic and from anaerobic treatment of solid wastes. A particular problem, associated with the importance of the textile industry in Bradford, has been the high content of wool fats, lanolin, produced during woolcombing and discharged into the sewage system. Although a number of sewage treatment works are still active in the District (see Chapter 11), by far and away the most important is the Esholt Works [SE 193 390]. The history of the site, nature of sewage and treatment processes are described fully by Anon (1947).

Sewage Works may contain sludges and solid wastes with high concentrations of heavy metals, filtered from the sewage, including cadmium, copper, lead, nickel and zinc, and acids used in water treatment. Filter beds and settling tanks may contain high levels of organic matter. When disused and buried, these organic deposits may slowly decompose under saturated conditions to produce nitrogen-rich leachate, methane, carbon dioxide and hydrogen sulphide (Knipe et al., 1993; Hooker and Bannon, 1993).

Iron Works/Foundries

Wastes from the iron and steel industry include slag, foundry sand and spent refractories which may contain high levels of heavy metals, such as chromium, lead, nickel and zinc, sulphates and sulphides, acids and alkalis, asbestos, solvents, phenols and hydrocarbons. Foundry sand often contains organic materials capable of generating methane (Hooker and Bannon, 1993). Large expanses of Made Ground are associated with wastes from the main iron works at Low Moor [SE 156 286], Bowling [SE 18 32] and Bierley [SE 170 285]. In 1835, alone, it is estimated that Low Moor Foundry produced 21 000 tons of waste, locally known as 'dross' (Richardson, 1976).

Specialist metalliferous industries, such as chromium-plating, generate wastes with high concentations of specific heavy metals.

Textile Industry

The District is famous as a centre of the textile industry, particularly in the production of worsted. Prior to the 19th Century, the production of textiles was very much a cottage industry, widely dispersed and unrecorded on available maps. The introduction of coal-fired steam power during the late 18th and early 19th Century, resulted in the concentration of the industry into large textile mills. These were abundant in most of the urban centres of the District, though the industry has undergone a significant contraction over recent decades and only a relatively few mills remain in production.

Mills may be involved in either the processing of wool to produce the yarn, or in the weaving of the yarn to produce the fabric. Information on the location of textile mills, derived from Ordnance Survey topographical maps, does not distinguish between different types of textile mill, or often between textile mills and corn mills. Richardson (1976, Figure 28) indicates the specific processes carried out in textile mills in Bradford, but not for the District as a whole.

The manufacture of worsted involves washing of wool in soap or degreasing solvents and hot water to remove the wool greases. The wool is processed to form yarn, which is treated chemically before being bleached and dyed. Most of the soap, wool greases, bleaches and excess dyes have been, historically, released into the sewage system for treatment at the Esholt sewage works, though residues may persist at mill sites. Metal-based dyes, such as iron sulphate (copperas), may persist as toxic residues (see Chemical Industry, below).

However, the bulk of the artificial deposits associated with the mills are cinders and ashes derived from the burning of coal in boilers, either to heat water for wool washing or to generate steam power for the looms. The ashes and cinders may contain concentrations of toxic heavy metals.

The leather industry is of lesser importance in the District, though tanneries formerly existed at Denholme Gate [SE 071 329] and High Royd Beck [SE 1815 2890]. Wastes derived from the tanning industry may include limeing waste, degreasing wastes containing solvents and tanning liquors, derived from the processing of hides in sulphuric acid.

Chemical Industry

A wide range of chemical works are present in the District, with a concentration in south Bradford. Many of these works were producing materials for the textile industry, such as dyes at Thornton Road [SE 146 335], bleaches at Burley Woodhead [SE 1594 4452], solvents, and vitriol or sulphuric acid at Canal Road [SE 166 338]. Contaminants often associated with products for the textile industry include boron, chromium, copper, mercury, zinc, acids, alkalis, benzene, toluene, solvents and phenols. Other chemicals produced include herbicides, at Wyke [SE 164 273], and chemicals for the paper industry, at Low Moor [SE 162 283] (Richardson, 1976). Low Moor was formerly the centre of an armament industry, with the production of explosives. Such sites may contain heavy metals, such as boron, chromium, copper, lead, mercury, nickel, zinc, and acids, alkalis, asbestos, toluene, solvents phenols, PCBs and hydrocarbons. Residues from these industries may be present in soils or percolate into groundwater in the vicinity of these sites.

Soils

Soils represent surface layers of bedrock or superficial deposits which have been altered by physical, chemical or biological processes. A soil profile comprises a series of horizons, more or less parallel with the ground surface, which pass down into unaltered parent material. Soils are formed by the physical shattering of rock by alternate freezing and thawing of water in pores and fissures, by chemical weathering through water containing dissolved oxygen, carbon dioxide and acids and by the effects of plant growth and decay to form humus (Carroll et al., 1979).

Generally, local soils are poor and naturally acid, partly due to the high silica content of the parent material and lack of neutralising minerals such as lime and also due to the high rainfall (Richardson, 1976). In a study of soils from the Bradford area, Richardson (1976) determined soil pH values of 5.0 to 6.0. The often relatively low temperatures in the District result in slow rates of soil formation, whereas the relatively high rainfall leaches soluble minerals, such as calcium, from the soil. Thin soils tend to develop on steep slopes due to the progressive downslope creep of soils as they develop.

Carroll et al. (1979) present a map, at 1:250 000-scale, showing the distribution of the main soil units present in the District, with descriptions of the typical controls on the formation of these soils. The main urban areas are not covered by this soil survey. The principal units present in the District are summarised in Table 7.

Well drained soils are well aerated and tend to be brown or red, e.g. brown earths and brown alluvial soils. Poorly drained soils form in anaerobic conditions with the reduction of ferric to ferrous iron resulting in the dominance of grey soils, known as 'gleys', e.g. stagno-podsols, stagnogley soils, stagnohumic gley soils and alluvial gley soils. When waterlogging is permanent, the decomposition of plant material is slow and organic matter accumulates to form peat.

Conservation sites

Tourism has flourished in the District over recent decades due to development of the area's rich industrial heritage, presented in many museums, and a starkly beautiful landscape with numerous conservation sites, both natural and archaeological. The conservation sites are not only recreational areas, but are also important as sites for research and educational purposes. A further important geological resource in the District is the geological museum at Cliffe Castle, Keighley. The museum contains an important collection of specimens of local rocks, specimens and fossils, including the holotype labyrinthodont *Pholiderpeton scutigerum* Huxley. Details of the collections held in the museum are provided by Armstrong (1979).

A hierarchy of earth science conservation sites has evolved over recent decades. Sites of Special Scientific Interest (SSSIs), have been designated by English Nature, or its predecessor the Nature Conservancy Council (NCC), on account of their special geological or geomorphological interest. These sites, of which three are located in the District (Table 8), have the status of statutory protection.

Sites of Ecological or Geological Importance (SEGIs) represent sites which have been recognised by the Local Authority to have special ecological or geological importance. Although these sites have no statutory protection, they are presented on the District deposit draft Unitary Development Plan, and the impact on the sites of any development is taken into account by Local Authority planners. Twenty one sites designated as SEGIs are listed on Table 9. Most of the SEGIs have been designated on the basis of ecological importance. However, a number of

Table 7 Principal soil types and their lithology, typical environment of formation and common land-use (after Carroll et al., 1979).

Environment & Location	Land-use	Lithology	Soil Group
Upland areas of permanent grass with high rainfall, on steep slopes or on well-drained sandstone dipslopes, e.g. Denholme, Cullingworth	Permanent grass, uncultivated or pasture	Loamy; on sandstone, shale or head	Brown earths; acid and well drained
River floodplains with permeable alluvium e.g. Wharfedale	Arable and grassland	Sandy to fine loamy; on river alluvium	Brown alluvial soils
In moorland where shale occurs beneath sandstone scarps, e.g. edges of Rombalds Moor	Limited grazing	Stony, loamy or sandy; on head	Stagno-podzols; peaty topsoil ± gley above thin ironpan
Pennine footslopes with gentle to moderate slopes, used for pasture, e.g. Silsden.	Permanent grass for pasture	Loamy or clayey; on till, head or shale	Stagnogley soils; anaerobic horizons
Upland moorland areas with gentle slopes, high rainfall and poor drainage, e.g. Rombalds Moor	Wet heathland or rough pasture	Loamy or clayey, on till or head	Stagnohumic gley soils; organic; poorly drained
River floodplains with high groundwater levels, typically permanent grass or marsh, e.g. upper Airedale	Poor permanent grass or marsh	Silty or clayey; on loamy or clayey river alluvium	Alluvial gley soils; anaerobic
Peat covered upland plateaux with high rainfall, e.g. Keighley & Oxenhope moors	Open moorland for rough grazing, water catchment, grouse shooting	Peat, lacking earthy topsoil	Raw peat soils; partly decomposed organics, anaerobic

the sites are of considerable geological significance. Baildon Moor has the remnants of numerous old coal pits and medieval ironstone pits and bloomeries. The crags at Shipley Glen provide excellent exposures of the Rough Rock and examples of glacial striations. Chellow Dene represents a classic example of a glacial drainage channel.

In addition, a number of Special Landscape Areas (SLAs) are designated and presented on the draft deposit Unitary Development Plan. Furthermore, the Local Authority is to designate a list of locally important nature conservation areas, which will often be more important for their social and amenity value than purely scientific basis. These will include urban green spaces, school nature reserves, allotments, churchyards, mill ponds, urban woodland and wildlife corridors. Although these will have no statutory protection, they will be taken into consideration in the planning process.

In 1990, the then Nature Conservancy Council established the Regionally Important Geological/Geomorphological Sites (RIGS) scheme. The scheme allows individuals or parties interested in geological conservation to identify sites, survey them in order to assess their regional significance, and notify the Local Authority (Carson, 1995). RIGS can be designated on the basis of their scientific or educational value, historical or cultural associations and aesthetic value. The scheme does not aim to prevent development on a RIGS, but allows the Local Authority to make an informed decision on if and how development should proceed (Carson, 1995). A programme of identification of RIGS sites is underway in the District. From the current study a number of important sites have been identified and are listed in Table 10. Many of the sites identified as of importance to earth science research and teaching are disused quarries and pits. There is increasing pressure to use such sites for landfill, particular those sites near to urban centres.

Summary and recommendations

The District comprises an almost complete stratigraphic sequence of Millstone Grit and Lower Coal Measures strata, consisting of interbedded sandstone, siltstone, mudstone, coal, seatearth and ironstone. The strata are disturbed by numerous faults, many of which have large displacements. Over much of the District the bedrock geology is overlain by natural drift deposits, both glacial and post-glacial. Locally, the drift deposits fill deep buried valleys, with in excess of 50 m thickness of deposits proved in Airedale and Wharfedale. Artificial (man-made) deposits are largely associated with areas of urban development and mineral extraction. Soils are generally poor, naturally acid and tend to support only pasture. The variability of the geology in the District and the presence of numerous exposures, particularly associated with quarries and pits, makes the District of importance in earth science research and teaching.

The main recommendations concerning issues discussed in this chapter include:

1. The position of bedrock geological boundaries and faults shown on the Bedrock Geology Map (Map 2) and drift and artificial (man-made) deposits shown on the Superficial Deposits Map (Map 3) are derived from several sources of data. These maps provides only a summary of the information held by the British

Table 8 Location of Sites of Special Scientific Interest (SSSIs) in the District.

SSSI	**Grid Reference**	**Conservation interest**
Bingley South Bog	[SE 114 386]	Wetlands environment; floral and faunal habitat
Yeadon Brickworks	[SE 193 408]	Former type section of Millstone Grit & railway cutting of Yeadonian (upper-most Namurian) age
South Pennine Moors	[SE 01 36]	Moorland environment; floral and faunal habitat

Table 9 Sites of Ecological/ Geological Interest (SEGIs) in the City of Bradford Metropolitan District.

SEGI	**Grid Reference**	**Importance**
Goitstock Woods	[SE 080 372]	Broadleaf woodland
Hirst Wood	[SE 127 383]	Mixed deciduous woodland
Baildon Moor	[SE 147 409]	Mire habitats
Ben Rhydding	[SE 144 478]	Former gravel pits forming open water and marshy grassland habitats
Leeds-Liverpool Canal	[SE 04 36] to [SE 19 38]	Wetland habitat
Coppice Bog and Pond	[SE 087 388]	Mire habitat and ornamental pond
Hallas Rough Park	[SE 055 359]	Heathland and mire adjacent to disused quarry
Hawksworth Spring Wood	[SE 160 409]	Mixed deciduous woodland
Shipley Glen	[SE 131 388]	Mixed deciduous woodland, moorland heath, grassland and marshland
Black Carr Wood	[SE 207 319]	Broad leaved woodland
Chellow Dene	[SE 123 346]	Fern communities
Miles Rough	[SE 120 359]	Glacial drainage channel with grassland, heathland, marshland and open water habitats
Brown Bank Marsh	[SE 060 482]	Reedswamp and marshy grassland
Castlefields Marsh	[SE 095 409]	Marshland
Middleton Woods	[SE 120 487]	Mixed broadleaved woodland
Newsholme Dean	[SE 015 403]	Heathland, birch woodland, grassland
Steeton Reservoir	[SE 022 430]	Open water and mire-type habitats
Sunnydale	[SE 101 433]	Woodland, grassland, heathland and wetland habitats
Beechcliffe Ings	[SE 061 426]	Ox-bow lake
Holme House Woods	[SE 039 407]	Mixed deciduous woodland and grassland habitats
Marley Bog	[SE 087 406]	Marshland

Table 10 Sites identified as having importance to earth science research and education.

Geological Stage	Geological Unit	Site name and location	Grid Reference	Earth Science Interest
Langsettian (Westphalian A)	Grenoside Sandstone and Greenmoor Rock	**Horton Bank Reservoir**, Great Horton; disused reservoir	[SE 125 307]	Key site for proving two distinct source areas for Lower Coal Measures; excellent sedimentological structures, trace fossils and palaeosol
	Elland Flags, Greenmoor Rock and Grenoside Sandstone	**Westroyd Hill**, Pudsey; disused railway cutting	[SE 213 323]	Key site for proving two distinct source areas for Lower Coal Measures
	Elland Flags	**Ellcliffe Quarry**, Allerton; disused quarry	[SE 115 347]	Open sandstone adit
	Stanningley Rock and 48 Yard Rock	**Wrose Brow**, Shipley, disused clay pit	[SE 156 371]	Sedimentary structures and stratigraphical significance
Yeadonian	Rough Rock Flags	**Cuckoo Park Farm**, Haworth; disused quarry	[SE 047 357]	Sedimentary structures and growth faults
Marsdenian	Woodhouse Grit Flags	**Penistone Hill Country Park**, Haworth; disused quarry	[SE 024 365]	Sedimentary structures
Marsdenian and Kinderscoutian	Woodhouse Grit and Flags, Bluestone and Kinderscoutian sandstones	**Ponden Clough**, Stanbury; valley	[SD 980 363] to [SD 987 368]	Important stratigraphical section
Kinderscoutian	Kinder-scoutian sandstones	**Dimples End Quarry**, Haworth	[SE 025 371]	Stratigraphical section and large tree roots

Geological Survey, who should be consulted if more detailed maps or additional data are required. It is important to note that during a geological survey, it is often difficult to precisely locate such geological boundaries or faults without a thorough site investigation. Where the nature of the bedrock or superficial deposits are of significance to a development, it is important that a site investigation is carried out to assess the geology.

2. The Superficial Deposits Map (Map 3) provides information on the distribution of artificial (man-made) deposits, but not its composition. Land-use categorisation was presented on Map 3 to provide a guide as to the possible nature of the artificial deposits. However, the map displays only a limited number of land-use types and should not be considered to be comprehensive. It is recommended that during the initial phase of a site investigation, the archival search should include a determination of former land-use. Artificial deposits may be highly variable in composition and the assessment of the nature of the deposit at a specific site, in particular with respect to ground stability and potential for contamination, should be ascertained through a thorough site investigation.

3. The District contains numerous geological exposures, particularly within active or disused quarries, which represent an important educational resource. It is important that the possible significance of geological sites are taken into consideration prior to any development of a site. English Nature, with the support of the National Association of Waste Disposal Contractors (NAWDC), advise that landfill operators contact the Local Authority, English Nature or RIGS groups to check the SSSI/SEGI/RIGS status of a site before infill commences. Further recommendations for landfill operators include consideration of the conservation of important quarry faces, sponsorship of research or rescue fieldwork and encouragement of access to safe sites with provision of information boards.

7 Mineral resources

Introduction

Mineral resources are natural accumulations of minerals, or bodies of rock, that are, or may become, of potential economic interest as the basis for the extraction of a commodity. Soils, which have a bearing on the quality of agricultural land, are for the purposes of this report not considered a mineral resource.

Mineral reserves are those mineral resources which have been evaluated and are commercially viable to work. They are not discussed in this report as their identification depends on a relatively expensive evaluation programme involving measurement of the material available for extraction, its properties, market suitability and ultimately the revenue its sale will generate. In the context of land-use planning, however, the term 'mineral reserves' should strictly be limited to those minerals which have a valid planning permission for extraction.

The extraction of surface minerals conflicts with the demands from agriculture or urban development. Factors to be considered by planners and developers include the potential of new developments sterilising a mineral resource for a considerable period of time. Alternatively, extraction of mineral resources can lead to problematical engineering ground conditions, depending on the types and methods of infilling, and can act as a constraint to future development of a site (see Chapter 10).

The mineral resources of the District are confined to materials which are currently, or have been historically, worked. These include sandstone, fireclay, brick clay, coal and sand and gravel, each of which is described in turn, below. The extent of these resources is shown on Map 4 and summarised on Figure 13 (*see* rear of book), with an indication of where these resources have been worked at the surface. The underground mining of coal, fireclay and sandstone is considered in Chapter 8 and presented on Map 5. Minor surface workings in man-made deposits ('mine stone'), limestone and peat are not shown on Map 4, but are discussed in this report. A list of the operational mineral workings in the District is provided in Appendix 14.2.

Sandstone

The Carboniferous sandstones of the Millstone Grit and Coal Measures of Yorkshire have traditionally been extensively used as a source of building stone. The presence of quarries, known locally as 'delf' or 'delph', both working and disused, are a common feature of the landscape and West Yorkshire has perhaps the largest concentration of sandstone quarries in Britain. Sandstone from West Yorkshire is sold under the generic term 'York Stone'. Its wide use as a local building material gives a distinctive character to the architecture, but York Stone has increasingly found wider application elsewhere and has a good reputation for durability (Leary, 1986).

During the 17th Century an increasing number of domestic buildings began to be built from stone. Being bulky and costly to transport, especially with the poor transport network of the time, the stone was often worked in small quarries adjacent to the building under construction. During the 18th and 19th centuries local stone was used for roadstone, required for the construction of a new network of turnpike roads. Commonly, quarries were opened on unenclosed land and would be worked when roadstone was required. Demand increased for wallstone, in response to the Enclosures Act, and building stone for large-scale construction projects associated with the development of numerous reservoirs and viaducts for the new railway network. During the mid-19th Century large-scale commercial quarrying became established in the District as a result of improved transport routes, including the Leeds–Liverpool Canal, and a railway network centred on Bradford. Often, the location of the large quarries was influenced by proximity to these transport routes. These new quarries supplied stone to the fast developing towns of Bradford, Leeds and throughout the country. During the last 50 years these markets have declined, due to the replacement of stone as the principal building material by reinforced concrete and brick. However, over recent years there has been a revival in demand and, in addition, local planning regulations have promoted the use of local stone in sensitive architectural areas. There is a continuing demand for its use in prestigious developments and for renovation.

Carboniferous sandstones consist of sand-sized particles, and occasional larger pebbles, composed dominantly of quartz, but also with some feldspar, which are cemented, usually by silica, to a greater or lesser extent. The sandstones are typically buff-coloured, although locally grey, and vary from fine- to coarse-grained. These sandstones are very resistant to attack by acid rain water, though they readily discoloured from buff to black when exposed to the polluted atmosphere prevalent prior to the introduction of the Clean Air Act. Subtle differences in colour, texture and natural markings provide a range of attractive building stones suitable for walling, paving and cladding applications. Given a certain minimum strength and durability, the suitability of a sandstone for building stone depends largely on its aesthetic qualities and textural consistency and on the size of the block that can be produced.

According to bed thickness, the stone was worked for roofing slates (tilestone), paving slabs (flagstone), ornamental or monumental stone ('ashlar'), whilst associated cross-bedded sandstone, of poorer quality, was worked for wallstones or crazy paving (Godwin, 1984). Coarse-grained sandstones ('grits') were formerly worked for grindstones, pulpstones and millstones, hence the origin of the name Millstone Grit.

Where the bedding is widely separated and the sandstone bed free from fractures and discontinuities, it may be suitable for the production of block stone which is used for subsequent sawing, either captively or by stone merchants. In general the larger the block the greater the value per unit mass because the productivity of diamond sawing is improved with less waste. Block stone is often produced to customer requirements and because of the practical difficulties of handling very large blocks is sized at the quarry. Sawn sandstone is used for paving, cladding, walling and specialised masonry products, including lintels, sills and copings. Dressed sandstone is also supplied in a wide range

Plate 7 Hand parting of Elland Flags sandstones, at Deep Lane Quarry [SE 130 327].

Plate 7 Hand parting of Elland Flags sandstones, at Deep Lane Quarry [SE 130 327].

of finishes for general building and fireplace work, and natural stone for random walling stone and rockery stone. Mica is a common constituent of some sandstones and if present as micaceous bedding planes allows the stone to be easily split, or riven, by hand to produce flagstones. Natural riven paving flags, such as those produced from the Elland Flags (Plate 7), have attractive natural surface textures and find application for flooring both internally and externally. Flags of insufficient size, to be used as flagstones are sold for crazy paving for landscaping and patio work.

The development of sandstone quarries may be hindered by the presence of large iron concretions, locally known as 'mare-balls' or 'acre-spires', which are orange discoloured and highly weathered. These concretions often develop, preferentially, within particular sandstone beds, rendering these beds unworkable. In the Halifax area, these concretions were worked during the 19th Century as an iron oxide pigment, or 'ruddlestone', used for the decoration of doorsteps, hearths and window sills (Walton, 1940).

In general, the Carboniferous sandstones in Yorkshire are too weak and porous and susceptible to frost damage for them to be used for good quality 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.

There are currently 12 working sandstone quarries in the District (see Appendix 14.2). These range in size from small building stone operations, producing natural stone, to larger operations with either sawing facilities on site for the production of a wide range of masonry products or supplying block stone (roughly sized sandstone blocks) for transport or external sale to stoneworks elsewhere. Some of the larger quarries also produce significant quantities of crushed sandstone for aggregate use. Minor quantities of building sand are also produced, e.g. Naylor Hill quarry [SE 040 365] and Hainworth Shaw quarry [SE 066 388].

The distribution of unfilled quarries, presented on Map 4, indicates the extent to which most of the main sandstones of the Millstone Grit and Lower Coal Measures have been worked in the past. An indication of the former and current uses of the main sandstones is shown in Table 11.

The Woodhouse Grit/Woodhouse Grit Flags, Rough Rock/Rough Rock Flags and Elland Flags are the most extensively worked of the sandstones in the District, both historically and at present. These sandstones, discussed below, are considered to represent the main sandstone resource in the District, and only the extent of these sandstones is shown on Map 4. The distribution of other sandstones is presented on Map 2.

Woodhouse Grit/Woodhouse Grit Flags

The Woodhouse Grit comprises a coarse-grained, massive or cross-bedded sandstone, underlain by the Woodhouse Grit Flags, which consists of fine- to medium-grained, flaggy or cross-bedded sandstone.

The Woodhouse Grit is worked at the Naylor Hill quarry, near Haworth [SE 040 365], as a source of building stone for the production of a wide range of sawn and naturally riven products. Sandstone unsuitable for building stone is crushed and screened and sold in various size ranges for aggregate use. Minor amounts of building sand are produced.

The Woodhouse Grit Flags from the Branshaw quarry [SE 034 402], at Oakworth, was formerly used in the construction of the new A629 in Airedale, but the quarry is now used as a source of block stone for the production of a wide range of masonry products. There is no stoneworks on site.

Rough Rock/Rough Rock Flags

The Rough Rock comprises a coarse-grained, massive or cross-bedded sandstone, underlain by the Rough Rock Flags, which consists of fine- to medium-grained, flaggy or cross-bedded sandstone.

The Rough Rock was extensively used in the construction of local domestic buildings and churches, particularly prior to the 18th Century. The sandstone is notably durable and little affected by moisture and was widely employed in the construction of warehouse basements, engine beds,

Table 11 The principal building stones of the City of Bradford Metropolitan District, with indication of their main uses, the approximate location of the resource and location of operational quarries. Note: additional small quarries may be worked intermittently for private consumption. Such sites are not included in this table.

Sandstone	Product	Resource Area	Working Quarries
Bradley Flags	Kerb stone Flagstone Building stone	Skipton Moor	None
Nesfield Sandstone	Kerb stone Flagstone Building stone	Silsden	None
Middleton Grit	Kerb stone Flagstone Building stone	Silsden	None
Kinderscoutian Sandstone	Building stone setts Pulping stones Millstone Ashlar Crushed stone Pitching stone	Eastburn Rombalds Moor Haworth	None
Bluestone	Road aggregate	Keighley	None
Woodhouse Grit Flags	Flagstone Paving flags Ashlar	Haworth	Branshaw
Woodhouse Grit	Building stone Ashlar Crushed stone	Oakworth Haworth Cullingworth Keighley	Naylor Hill
Rough Rock Flags	Flagstone Building stone Ornamental Paving stone	Oxenhope Moor Cullingworth Bingley	Nab Hill Hainworth Shaw Apperley Midgeham Cliff End
Rough Rock	Building stone Crushed grit Kerbs	Shipley Cullingworth Rawden Keighley Bingley	Buck Park Bank Top
Elland Flags (Gaisby Rock)	Flagstone Ashlar Building stone Kerbs Pitching stone Roof tiles Paving stone Crushed stone	Thornton Queensbury Fagley Idle Bradford	Bolton Woods Deep Lane Chellow Grange Ten Yards

dock gateways and bridge foundations (Brigg, 1873). However, the hardness of the sandstone made it unsuitable for delicate work, and it was replaced by the Elland Flags as the main building stone in the District.

The Rough Rock is still worked at Buck Park quarry [SE 071 352], near Cullingworth. This is one of the largest quarries in the District, producing crushed and screened sandstone in various size ranges for selected fill. The sandstone is too coarse-grained for use in the production of building sand. The quarry is also an important source of block stone for external sale to stoneworks. The Rough Rock is also worked for walling and flagstone at Bank Top quarry [SE 091 375], near Harden.

The Rough Rock Flags are worked for walling and flagstone at Apperley quarry [SE 196 390], near Rawdon, and Nab Hill quarry [SE 035 324], to the south of Oxenhope. At Hainworth Shaw quarry [SE 066 388], near Keighley, the Rough Rock Flags are poorly cemented, locally, and selected material is crushed and ground for the production of building sand. Some block stone, for external sale, is produced from the harder sandstone beds, together with material for random walling. Until recently this sandstone was also worked at the Midgeham Cliff End quarry [SE 072 383], on Harden Moor, for building stone. There are also proposals to reopen the old Flappit Spring quarries [SE 055 356], on Hallas Rough Park, for the production of naturally riven flagstone from the Rough Rock Flags.

Elland Flags

This is the main Lower Coal Measures sandstone to be worked in the District. The lower leaf, locally often referred to as the Gaisby Rock, was most often quarried, and locally mined (see Chapter 8). The Elland Flags comprise fine- to very fine-grained sandstone with the best quality

Plate 8 Two leaves of the Elland Flags exposed in the operational Bolton Woods South Quarry: Berry and Marshall (Bolton Woods) Ltd, with redundant crushing plant in the foreground.

stone having a well developed planar bedding, which allows parting by hand (Plate 7). In Bradford, the prized stone occurs as only thin bands, often near to the top of the main lower leaf, divided by bands of inferior sandstone, referred to as 'ragstone' by quarrymen (Godwin, 1984).

The flagstones were worked for paving flags, steps and road kerbs. The Elland Flags have been extensively used in London as paving flags because of their durability, colour and non-slip properties (Ashurst and Dimes, 1990). Although used for tilestone in older buildings, the Elland Flags are considered to be rather unsuitable because of their heaviness and tendency to hold water (Ashurst and Dimes, 1990). Large blocks of massive or freestone, known as 'ashlar', were sawn to form stone vats for dyeing and brewing and stone troughs (Walton, 1940). In buildings, ashlar was used mainly for dressings, sills and coping stones.

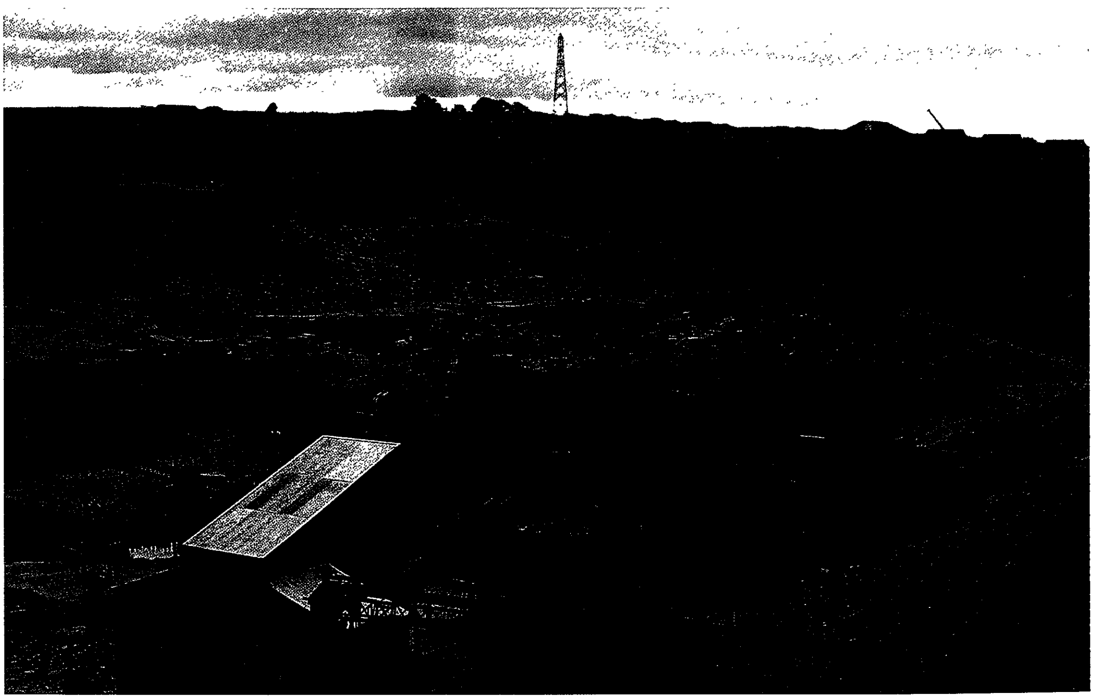
The Bolton Woods area of Bradford has been a major centre of sandstone production, at least since the mid-18th Century. The 'Spinkwell Stone' from the now backfilled Spinkwell and Cliff Wood Quarry [SE 168 344], comprised a grey, compact, fine-grained stone, worked for flagstone and building stone and used in the construction of Manchester Town Hall (Ashurst and Dimes, 1990). The Bolton Woods North quarry [SE 163 365] was, until recently, a major source of sandstone for paving, cladding, ashlar blocks and a range of masonry products. However, the site is now exhausted and quarrying operations ceased in early 1994 and processing on site at the end of February 1995. The Bolton Woods South quarry [SE 163 362] is one of the largest sandstone quarries in the District (Plate 8), the bulk of the output being crushed and screened sandstone sold in different size fractions for selected fill and, occasionally, sub-base for roads. The basal beds of the quarry are also an important source of large block stone which is transported to the company's Fagley Lane plant for sawing and masonry work. The quarry also supplies flagstone for crazy paving. Dimension stone, worked at Bolton Woods South quarry, was used in both Bradford and Leeds town halls (Ashurst and Dimes, 1990). The Elland Flags at the Deep Lane quarry [SE 130 327], at Crossley Hall are an important source of natural riven paving flags (Plate 7). Fagley quarry [SE 186 352] at Eccleshill is currently not being worked but contains reserves of building sandstone. The small Chellow Grange quarry [SE 121 355], at Chellow Heights, also supplies walling stone and flagstone. Natural riven flagstone and walling stone are also produced at the Tenyards quarry [SE 080 340], near Denholme.

Fireclay

The term 'fireclay' was originally applied to refractory clays used for lining furnaces and making crucibles. Until comparatively recently the term was also used to refer to the unbedded mudstones containing rootlets (Stigmaria) which typically occur beneath coal seams, irrespective of their refractory properties. These rootlet beds are now known as seatearths, or seatclays where clay-rich, and the term fireclay is now generally used only where the clays are, or may be, of commercial interest (Highley, 1982). Seatearths exhibit a wide variation in composition and where highly siliceous were known as 'ganister,' also formerly valued as a refractory raw material. The name of a particular fireclay is derived from the overlying coal. Seatclays, and thus fireclay resources, are mainly confined to the Westphalian (Coal Measures), the major coal-bearing stage in Britain and in the Bradford District occur in the Lower Coal Measures.

Fireclays consist principally of disordered kaolinite, hydrous mica and quartz in varying amounts; the relative proportions of these, together with their grain size and the amount and type of impurites present, having a marked effect on the ceramic properties and value of the clay. Refractoriness is normally a function of a high alumina content, and thus the proportion of kaolinite present, together with a relative absence of fluxes, such as potash and soda which occur associated with mica. Fluxes reduce the vitrification temperature of a clay and thus have a marked effect on refractory properties. Siderite, present as both clay ironstone nodules and sphaerosiderite less than 1 mm in diameter, and carbonaceous matter, present as coaly material and fossil debris, are common accessory materials and may represent serious impurities. Fireclays

Plate 8 Two leaves of the Elland Flags exposed in the operational Bolton Woods South Quarry: Berry and Marshall (Bolton Woods) Ltd, with redundant crushing plant in the foreground.



may exhibit both lateral and vertical variation in quality, both in the proportions of the component minerals present, and in the amount and type of impurities. No single fireclay is, therefore, suitable for all applications (Highley, 1982).

Historically, fireclays were valued as a refractory raw material and they were formerly widely used in the production of a range of firebricks and other refractory goods. Subsequently they were also used for other purposes, including the manufacture of salt-glazed pipes and sanitaryware. Some fireclays have relatively low iron contents compared with other clays and are valued for the production of buff-coloured facing bricks. Today this is their major use together with the manufacture of vitrified clay pipes. Fireclay formed the basis of an important extractive industry in Britain in the 19th and first half of the 20th centuries with production from most of the coalfields. The bulk of the output was obtained by underground mining and this was the case in the Halifax–Bradford–Leeds area. Here many of the fireclays were mined independently of the coal seams, which below the Elland Flags are generally thin and of poor quality. However, demand for fireclay refractories has declined markedly since the late-1950s, due chiefly to changing technology in the iron and steel industry, which has resulted in more severe operating conditions requiring higher quality refractories. In addition, many of the other traditional uses of fireclay refractories, such as in the production of firebricks for domestic use, steam engines, ships boilers and the carbonising industry, have all virtually ceased. In the non-refractory sector, pipemaking technology has also changed and salt-glazed pipes have been replaced by vitrified clay pipes, which utilise a wider range of clays. In addition, the advent of opencast coal mining during the Second World War, together with the high and rising cost of underground mining and the declining demand for fireclay in many of its traditional applications, caused a marked decline in the number of underground fireclay mines. Today, therefore, UK production of fireclay is derived almost entirely as a by-product of opencast coal mining.

In the Halifax–Bradford–Leeds area all the fireclays from the Soft Bed to the Better Bed have been worked in the past. In the western part of the area, the most important fireclays are associated with the Hard Bed and 36 Yard coals. The latter has a high alumina (>32 per cent) and low alkalis (<1.0 $K_20 + Na_20$) content and was formerly worked just outside the District from small drift mines in Halifax, for the manufacture of refractory bricks. In contrast the Hard Bed fireclay is a siliceous clay which, despite a relatively low alumina content, is unusual in having low alkalis and iron contents (Table 12). It is the only fireclay that has been worked in the Bradford District for the past few years, extraction being from the small Dog and Gun quarry [SE 093 343] at Oxenhope where the bed is in excess of 1.1 m thick.

The Hard Bed fireclay has been used for nearly 200 years by Halifax-based Parkinson-Spencer Refractories for the manufacture of glasshouse pots, a refractory pot used for melting speciality glasses such as lead crystal glasses (Parkinson, 1989). Selectively worked fireclay from the Dog and Gun quarry is blended with similar clay mined in the Shibden valley, near Halifax. Total annual output is only about 1200 tonnes. The advantage of siliceous clay with a low iron content is its ability to dissolve into the glass without causing contamination.

The Better Bed fireclay was also formerly extensively worked for the manufacture of refractory goods and sanitaryware, production being mainly in the Tong area, where the fireclay was between 0.6 m and 0.75 m thick. White (1970) studied the geological, mineralogical and economic relationships of this fireclay and associated coal in the Tong area. Deep mining of the Better Bed coal and fireclay ceased in the late 1950s on economic grounds, and was replaced by opencast mining which continued until the late 1970s. A mean analysis of the Better Bed fireclay is shown in Table 12 (White, 1970), suggesting a chemical similarity with the Hard Bed fireclay. The Better Bed Coal (low sulphur and high calorific value) was so-named because it was stratigraphically the lowest coal of high quality in the Lower Coal Measures.

Coal

Coal is no longer worked in the District, though its extraction was formerly of great importance to the industrial development of Bradford. The majority of coal was worked underground, either from bell-pits, adits or shafts. The history of coal mining, the techniques employed and the distribution of workings are discussed in Chapter 8.

The former use of the principal coals is presented on Table 5 (Chapter 6). The lowest Coal Measures coal seam, the Soft Bed Coal, was formerly worked for its low sulphur content. The Middle Band Coal is usually only a few centimetres in thickness and was not worked, with the exception of the area of Soil Hill [SE 070 317], where the coal locally thickens to 0.8 m. The Hard Bed Coal has been extensively worked both at outcrop and in mines, despite having a high sulphur content. This coal is readily distinguishable by the presence of the Listeri Marine Band above the coal. The Better Bed Coal has been extensively mined in the District and is noted for its low sulphur content. The Black Bed Coal was the most important coal to be worked during the latter stages of mining in the District. It was commonly worked along with a thick ironstone, particularly in the Low Moor area. A number of younger coals, including the Crow Coal, Shertcliffe Coal and Blocking Bed Coal, have been worked, to a limited extent, in the area to the south-east of the City of Bradford.

Modern opencast coal mining started as an emergency measure during the Second World War. At this time, a number of sites in the District were prospected as potential sources of opencast coal. Only one of these considered the viability of Millstone Grit coals; that at Holden [SE 070 445], in the Rough Holden Coal. Despite being

Table 12 Typical chemical analyses of fireclays.

	Wt%	
	1	2
SiO_2	71.69	66.5
Al_2O_3	25.25	21.0
Fe_2O_3	1.50	1.4
CaO	0.18	0.12
MgO	0.16	0.31
Na_2O	0.43	0.16
K_2O	0.60	0.69
TiO_2	tr	1.2
Loss on ignition	—	8.7

1. Hard Bed (calcined). Parkinson-Spencer Refractories Ltd.
2. Better Bed, Tong.(uncalcined) mean analysis over bed thickness (White, 1970).

about 1.4 m thick, the coal was considered to be of insufficient thickness when account was taken of the presence of old workings and a high proportion of hard rock overburden.

The other prospected sites were from coals in the Lower Coal Measures. These included:

- Denholme [SE 066 346], in the Soft Bed and Hard Bed coals, prospected in the 1940s. The ground was faulted and the Hard Bed Coal had been partly extracted in underground workings.
- Bowling [SE 19 31], in the Shertcliffe Coal, prospected in the 1940s.
- Back Lane [SE 220 313], in the Better Bed, prospected in the 1940s.
- Black Carr [SE 205 319], in the Better Bed, prospected in the 1940s.
- Tramway [SE 210 315], in the Better and Black Bed coals, prospected in the 1940s.
- Tong [SE 225 310], in the Crow and Black Bed coals, prospected in the 1960s. The Crow Coal comprised several thick dirt partings, with a total thickness of coal of about 0.8 m. The coal has a high ash and sulphur content, and only the upper 0.3 m was suitable for domestic purposes. The Black Bed, comprises about 0.6 m of coal, high in sulphur.
- Charles [SE 213 310], in a thin coal above the Shertcliffe Coal, prospected in the 1960s.

Opencast coal mining only occurred at Back Lane and Tramway, with additional sites at North Wood [SE 226 314] and Hollin House [SE 237 311]. These operations commenced in the 1950s, with the Leeds Fireclay Co. Ltd working the Better Bed and associated fireclay. The company ceased production in 1976, though extraction by J H Hayes Contractors Ltd continued at the North Wood Site for a short time afterwards. As the name suggests, the Better Bed is one of the highest quality coals in Yorkshire, with a high calorific value and low ash and sulphur content. Values quoted by White (1970) for the Better Bed at Tong are;

Calorific value	31.4 to 34.9 GJ/tonne
Ash content	5% (mean)
Sulphur content	0.9 to 1.2%

No attempt has been made to delineate on Map 4 the extent of coal resources in the District. Only the extent of known surface workings are shown on this map. The Mined Ground and Shafts Map, Map 5, shows the extent of areas in which worked or potentially worked coal seams occur within approximately 30 m of the ground surface. This gives an indication of the location of shallow coal.

Opencast coal is a relatively low cost source of energy. Although the boundaries of opencast sites are limited by surface developments, such as roads, railways, urban areas and also overburden ratios, a high proportion of the coal is recovered. Often thin seams can be recovered if of adequate quality. Thus most of the coal produced by opencast mining could not be recovered by deep mining.

Sand and Gravel

Deposits of sand and gravel, associated with superficial deposits, have been worked to a limited extent in the past, although no workings are currently operational. Sand and gravel is used in the construction industry. The principal uses of sand are as a fine aggregate in concrete, in mortar and in asphalt, and the main use of gravel is as concrete aggregate. Sand and gravel is also used as a source of constructional fill.

Resources are largely confined to the alluvial floodplains and terraces of the rivers Wharfe and Aire and it is only these that have been shown on the Mineral Resources map (Map 4). Narrow tracts of Alluvium present in tributary valleys have been omitted because of their limited areal extent. These areas are shown on the Superficial Deposits map (Map 3).

The deposits include Alluvium and River Terrace Deposits comprising silt and fine sand with gravel lenses. These deposits may be underlain, locally, by Glaciofluvial Deposits, which in Wharfedale comprise predominantly gravel with sand lenses (Price et al., 1984). A resource study of the area between Ilkley and Burley-In-Wharfedale, shows that the sand and gravel deposits vary in thickness rapidly and may thin out completely within a short distance (Price et al., 1984). Boreholes and resistivity soundings indicate sand and gravel ranging from 1.5 m to 14.0 m in thickness, with a mean of about 6 m and that an overburden to sand and gravel ratio of better than 1:1 could be expected. The main constituent of the gravel fraction is limestone, but sandstone is also abundant, some of which is friable (Price et al., 1984).

Former workings in the alluvial gravels of the River Wharfe, present to the east of Ilkley [SE 144 480], were dredged from shallow pits until the 1950s. In Airedale sand was worked at Bingley for use in the construction of the railway in 1847.

Significant thicknesses of Glaciofluvial sand and gravel deposits may occur beneath Alluvium and River Terrace Deposits, in both Airedale and Wharfedale. However, these deposits may occur as deeply buried lenticular bodies which are not easily found and their extent, thickness and overburden ratios are generally not known. In the Keighley area, overburden is in excess of 30 m in places, which is likely to preclude working of the deposit.

Small areas of Glaciofluvial sands and gravels also occur on the interfluves, and limited working of the sand has been recorded at Gooseye [SE 032 405], worked until recently, and Lower Grange [SE 125 332], the latter comprising between 7.5 m and 9 m of sand and gravel. These areas of Glaciofluvial sands and gravels have been omitted because of their limited size. However, these areas are shown on the Superficial Deposits map (Map 3).

Brick clay

The working of clay for brick making is now defunct, and historically was only of minor importance because of the local availability of sandstone for building purposes. Much of the demand was from collieries, which required a cheap building material for the construction of miners' cottages, colliery buildings and underground workings (Smith, 1974; p.365). The improvement in the transport network during the latter part of the 19th Century and 20th Century, resulted in the small-scale local brickyards closing, under competition from the large-scale operations from elsewhere in the U.K.

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 the mudstones and Till in the District, therefore, limits its future use.

Whilst Carboniferous mudstones 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 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.

Mudstones from throughout the geological sequence, including both the Millstone Grit and Lower Coal Measures were formerly worked in the District. It is probable that proximity to the centre of demand, rather than the suitability of the mudstone, was formerly the principal factor in the location of brick pits.

Millstone Grit

- Lower Marchup, Addingham [SE 055 489] — mudstone above the Marchup Grit
- Park Wood Brick Pit, Keighley [SE 067 408] — mudstone above the Bilinguites gracilis Marine Band
- Bingley Brick Pit [SE 112 412] — mudstone above the Cancelloceras cancellatum Marine Band

Lower Coal Measures

- Wrose Brow Brickworks, Shipley [SE 160 374] — from below the Hard Bed Coal
- Wrose Hill Fireclay Co. Ltd, Shipley [SE 155 370] — from above the Hard Bed Coal
- Barkerend [SE 174 330] and [SE 176 331] — from beneath the Greenmoor Sandstone and Grenoside Rock, respectively
- Crossley Hall, Faiweather Green [SE 132 333] — from below the Black Bed Coal
- Staygate [SE 163 307] and Bowling Park Brick Works [SE 167 305] — from above the Black Bed Coal
- Haycliffe Hill [SE 142 310] — from below the Clifton Rock
- Victoria Brick Works [SE 181 305] — from above the Shertcliffe Coal

Locally, the glacial Till deposits were sufficiently clayey to have been worked for brick clay at Laisterdyke Brick Works [SE 195 334]. Clay-rich Till deposits have also been extracted at West Hills [SE 108 347], prior to use of the site for landfill, to use as a 'puddling clay' during the recent re-routing of the Leeds–Liverpool Canal at Bingley.

Mudstone and fireclay associated with the Hard Bed Coal have been used in the past in the manufacture of coarse, domestic earthenware. A particular centre for the trade was at Denholme, which formerly produced large quantities of 'black pottery', including flower pots, pitchers and bottles (Brigg, 1874).

Other Mineral Resources

Peat

Peat occurs as thin veneers across parts of the upland areas of the District. Despite the thinness and limited extent of the resource (see Chapter 6), Peat was formerly worked for fuel, but is unsuitable for horticultural purposes. Peat extraction was of limited scale, worked for local consumption in farmsteads, in remote upland areas where there were no workable coal seams and transport of coal was expensive. The traces of former peat-cuttings are located at Rombalds Moor [SE 101 462], and includes areas of 12th Century monastic workings, at Foreside [SE 056 318], worked until early this century, Middle Moor [SD 991 346] and Oxenhope Moor [SE 021 331] and [SE 013 327] and The Sea [SD 974 395].

The historic extraction of Peat has had a detrimental impact on the environment, leaving patches of ground comprising coarse sand and sandstone fragments without a soil horizon, hindering the re-establishment of vegetation cover. Further working of Peat is unlikely.

Made Ground

Large quantities of waste material from sandstone quarries and underground coal workings exist in the District. Some quarry spoil comprises almost entirely of waste sandstone blocks. The original quarrying would have worked a specific sandstone, either with certain thickness of parting or uniform colour, and discarded the remainder. During the early 20th Century, a demand for building stone of the once discarded iron-stained 'red stone', resulted in the raking over of old spoil heaps in West Yorkshire (Walton, 1940). Also, waste stone was crushed to provide concrete aggregate during the early 20th Century, though West Yorkshire Carboniferous sandstones are too weak and susceptible to frost damage to be used in high quality concrete. However, the inert nature of sandstone spoil makes them ideal for bulk-fill, in particular for the construction of road embankments.

Colliery spoil, or mine stone, consists of shale, siltstone, sandstone, ironstone, waste coal and fireclay. Mine stone can be utilised as fill, though the use is limited and requires controlled usage. Detrimental effects to concrete foundations may result from the decomposition of disseminated pyrite to iron sulphate. Waste coal or carbonaceous matter may generate methane and possibly undergo combustion unless precautions are taken to exclude air. Burnt shales are more suitable for bulk-fill purposes, as combustion has already removed the carbonaceous material from the spoil. A mound of burnt colliery spoil at Baildon Moor [SE 140 402] has been excavated for path construction (Plate 6).

Limestone

Limestone bedrock does not occur at outcrop in the District, the nearest supply coming from Skipton. However, Hummocky Drift Deposits present in Airedale are often rich in limestone boulders, transported by ice from their source area in the north, during the last glacial period. During the 17th and 18th centuries, when transport was poor and costly, this local source of limestone boulders was extensively worked at Bingley [SE 113 387], [SE 106 383], [SE 109 388] and [SE 109 394]. The boulders were worked in pits or, through the construction of artificial ponds, which when the water was allowed to escape suddenly, washed away the lighter deposits and exposed the boulders. The boulders were crushed and burnt in limekilns, located near to the pits, to produce lime for agricultural use to help neutralise the acidic soils. The construction of the Leeds–Liverpool Canal and the establishment of the Bradford Lime Kiln Company in 1774, permitted cheap transport of limestone from Skipton and Bingley to areas of demand in Bradford for use as a flux in ironworks. The deposits have not been worked at Bingley this century and are unlikely to be of future economic importance.

Summary and recommendations

Sandstone is the main mineral resource in the District, and despite extensive quarrying in the past, large resources remain. Eleven quarries are currently operating, and demand for local stone is likely to continue in the near future. The main factors hindering further extraction are sterilisation of the resource by urban development and conflicts with other forms of land-use. As existing quarries become exhausted and in order to meet any future demand for stone products, it will be necessary for either new quarry sites to be found, or old sites reopened. As most of the potential sites are likely to be in rural parts of the District, there is likely to be conflict between mineral extraction and its possible detrimental effect on the landscape.

In order for an informed decision to be made on the most suitable sites for future operations, it is essential that the properties of the various building stones, and hence their suitability for different purposes, is known. As there is little widely available information on the properties of local sandstones, this project carried out a study of the properties of the main sandstone units in the District. The results of this study are presented in Appendix 14.5, which is aimed to provide a guide to sandstone properties. Additional testing at sites which may be proposed for future extraction is recommended in order to determine local variations in sandstone properties.

Nationally, production of fireclay is now almost entirely as a by-product of opencast coal mining and the mineral is used primarily for the manufacture of facing bricks and vitrified clay pipes. Opencast coal resources within the District are very small and thus potential by-product output of fireclay from this source is also small. Nevertheless, a planning application to work the Middle Band and Halifax Hard Bed coals and associated fireclays from a small site at The Shay, near Denholme [SE 075 316], has recently been made. There will be a continuing small demand for the Halifax Hard Bed fireclay for use in the manufacture of glasshouse pots.

Whilst coal has been an important mineral resource in the District for several hundred years, it is no longer worked. Underground mining of coal ceased in the 1960s and because of problems associated with thin coals, of poor quality, in an area of complex faulting, it is unlikely that such mining will be economically viable in the future.

There is, however, potential for future small-scale opencasting of coal. The economics of opencast mining have changed with time allowing coals with higher overburden ratios to be extracted. Therefore, sites prospected in the past, but thought to be uneconomic to work, may become viable in the future. Opencast coal resources are almost entirely confined to Coal Measures strata, which underlie a significant part of the southern and eastern parts of the District, either at the surface or beneath variable thicknesses of superficial deposits. Although large areas of shallow coal have been sterilised by urban development, potential opencast coal sites still remain. Alternatively, during any future redevelopment of urban areas, coal currently sterilised by surface development may become available for coal extraction. It is important that during the planning stages of major redevelopment schemes, that the potential for opencast coal extraction is considered. Elsewhere in the country, hazardous sites associated with derelict land have been significantly improved by the working and controlled restoration of opencast sites.

Sand and gravel resources in the District are relatively small and limited to Airedale and Wharfedale. These areas include the main transport routes and represent the prime areas for urban development. As a result, few areas of undeveloped ground are available for sand and gravel extraction. Areas such as Esholt [SE 19 39], comprise extensive tracts of alluvium and river terrace deposits, which may contain workable sand and gravel, but which has been inaccessible for nearly a century because of the presence of the large sewage treatment works. Nationally, demand for sand and gravel for aggregates is likely to remain high. Planners should take into account potential sand and gravel resources present in both of these valleys when considering redevelopment schemes. However, the limited extent and lateral variability of the deposits and often great thicknesses of overburden may hinder future development.

The main recommendations are:

1. As a future mineral resource, sandstone, fireclay, coal and sand and gravel need to be considered for possible protection. Sterilisation of mineral resources, through urban development or construction of new roads, is a potential issue of concern.

2. The sandstone properties study provides a general guide to the geotechnical and chemical properties of the main building stones of the District. However, only a small number of samples could be analysed for each sandstone and there is the possibility that the samples tested are unrepresentative. Even within individual quarries, the properties of sandstones may vary in response to degrees of weathering, proximity to faults, or localised lithological variations. If the load-bearing properties or chemical properties of sandstone worked in a quarry are a significant feature of the product, it is recommended that mineral operators assess the nature of their product through testing procedures described in Appendix 14.5.

8 Mined ground and shafts

Introduction

This chapter discusses the history and methods of underground mineral workings, the geological consequences of such workings, indicates methods used to investigate their presence and lists some of the remedial measures which may be used where old workings may be a problem. Map 5, summarised as Figure 14 (*see* rear of book), indicates areas where underground mining is likely to have taken place within the District.

Underground workings in the District are associated with either coal, and associated minerals of fireclay and ironstone, or sandstone. Ironstone and fireclay were sometimes extracted from the same mines as coal.

Most of the information on coal-based extents of workings and mine entries was derived from British Coal data, at 1:25 000 scale, now held by the Coal Authority. The extents of workings were derived from the mining reports database for the nine seams worked in the area; the original abandonment plans were not used in this study. Abandonment mine plans for ironstone and fireclay workings and coal seams in the Millstone Grit, collected from sources other than British Coal, were also incorporated into the database. Examples of colliery-based and sandstone mineplans are provided in Plate 9 and Figure 15. A number of coal-based shafts and adits, not identified in the British Coal database, were located on BGS fieldslips and maps and ground survey. Information on the extent of sandstone workings and location of sandstone shafts was largely derived from BGS records, local authority plans and the Mineral Valuer. A number of sandstone shafts were incorrectly identified as coal-based mine entries on the British Coal plans.

Information on the thickness ranges and former uses of coal seams is provided in Table 5 (Chapter 6), and is summarised on the Generalised Vertical Section (Figure 6). The geological memoirs for Bradford (Stephens et al., 1953) and Huddersfield (Wray et al., 1930) remain the most detailed published descriptions of seam variation. Godwin (1984) provides the most detailed review of the sandstone mining in West Yorkshire.

Mining methods

The mining methods employed in the District have shown a relatively systematic development through time from surface workings, to shallow mining and to gradually deeper mining. An appreciation of the mining methods employed is helpful in understanding the possible condition of old workings below ground and hence their implications for planning, site investigation and development.

Coal, fireclay and ironstone

Historically, the main types of workings for these minerals include bell pits, pillar and stall workings and longwall methods. These are discussed below.

<u>Bell pits</u>
The earliest workings were restricted to extracting ironstone, coal and fireclay from near outcrop, and in valleys or slopes where drift deposits were absent or very thin. Bell pits were used from medieval times until as late as early 19th Century. Ironstone may have been worked as early as Roman times. By the 17th Century a flourishing rural iron industry existed in the District, with bloomery furnaces present on Baildon Moor. The extraction of coal in the District is known to have been carried out as early as 1230 and there are records of shallow pits at Stanbury in 1346 (Richardson, 1976). From the beginning of the 16th Century, coal exposed at the surface was dug extensively, largely for local domestic use to replace tree wood as the main fuel (Richardson, 1976).

Bell pits initiated from shafts about 1 metre in diameter and up to 10 metres deep. The working of coal from the base of the shaft created a bell-shaped void, with an unsupported roof to the coal seam (Figure 16). The excavated area of coal was roughly circular in plan and up to 6 metres in diameter, though maximum diameters of 8 to 20 m are recorded (Littlejohn, 1979). The seam was worked until the entire structure was in danger of collapse.

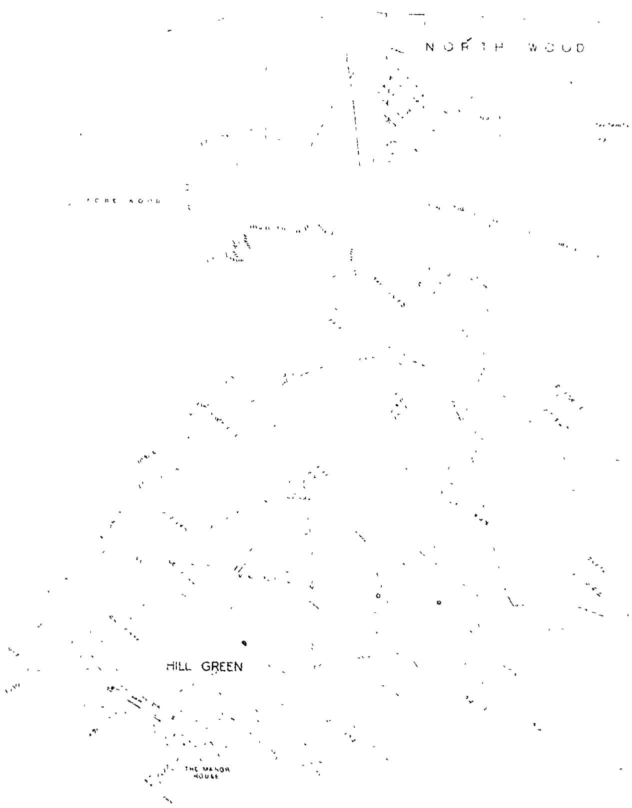
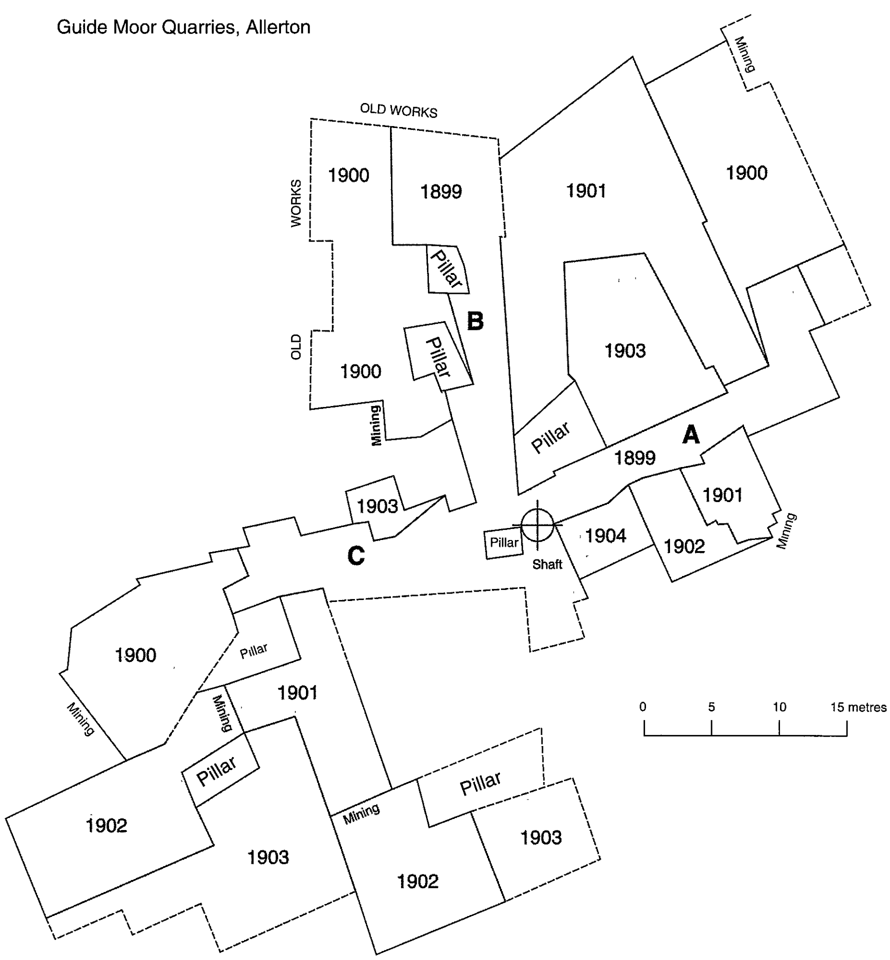


Plate 9 Example of part of an abandonment mineplan for Leeds Fireclay Co. at Tong, working the Better Bed Fireclay (reproduced with permission of Fennell, Green and Bates).

Figure 15 Example of a sandstone abandonment mineplan from Guide Moor, Allerton.



Extensive areas of bell pits are still evident at Baildon Moor [SE 14 40], Rough Holden [SE 07 45], Denholme Edge [SE 055 345] and Egypt [SE 094 391]. At Baildon Moor, the former shafts to bell pits are surrounded by a low mound of spoil (Plate 10), allowing the shafts to be identified from aerial photographs (Plate 11). However, elsewhere, bell pits are often associated with hummocky, disturbed ground in which it is difficult to distinguish between former shafts, areas of crown-holes, surface excavations and spoil mounds. In built-up areas, such as Bowling and Shelf, general landscaping and ground improvement has obliterated the surface features associated with bell pits.

Shallow mine workings: Pillar-and-stall (or stoop and room) workings

The pillar-and-stall method of mining was developed to gain access to deeper reserves of coal and ironstone. This system involved the working of coal and ironstone along a grid of roadways, with rectangular pillars of coal left for support, with waste material ('goaf') often stored in the voids (Figure 16). This method of working has been recently exposed in excavations at the Dog and Gun Clay Pit [SE 093 343] (Plate 12). Pillar-and-stall workings, widely employed in the District during the late 18th and early 19th centuries, were often owned by large companies, supplying coal and ironstone to specific local industries, such as textiles and ironworks.

Larger pillars are required to support the roof with increasing depth, and thus the pillar-and-stall technique was self-limiting in terms of economic usage. In West Yorkshire the maximum feasible depth may have been about 30 m (Giles, 1988). General dimensions of these workings in West Yorkshire (Bell, 1978) are summarised below:

- Workings penetrated only about 40 m from the shaft in the 15th Century, increasing to about 200 m by the 17th Century.
- Room size increased with time from, usually, less than 2 m wide in the 15th Century to a range of 1.8 to 5.0 m in the 19th Century.
- Extraction ratio ranged from 30% to 70%, showing a general increase with time.

Important factors controlling the dimension of the pillars and stalls include the strength and discontinuities in the roof rock, the thickness of seam and depth of the workings. The layout of the pillars and the orientation of 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.

Longwall mining

The longwall method of mining involved total extraction of a panel between two parallel headings (Figure 16). There was only temporary support of the roof, which was allowed to collapse as coal was progressively worked. This technique would have been widely employed in the deeper

Plate 10 A shaft location at Baildon Moor, showing a subsidence hollow

Plate 11 Aerial photograph showing location of bell pits at Baildon Moor, surrounded by low mounds of colliery spoil (reproduced with permission of City of Bradford Metropolitan Council, Transportation and Planning Division.

Plate 10 A shaft location at Baildon Moor, showing a subsidence hollow

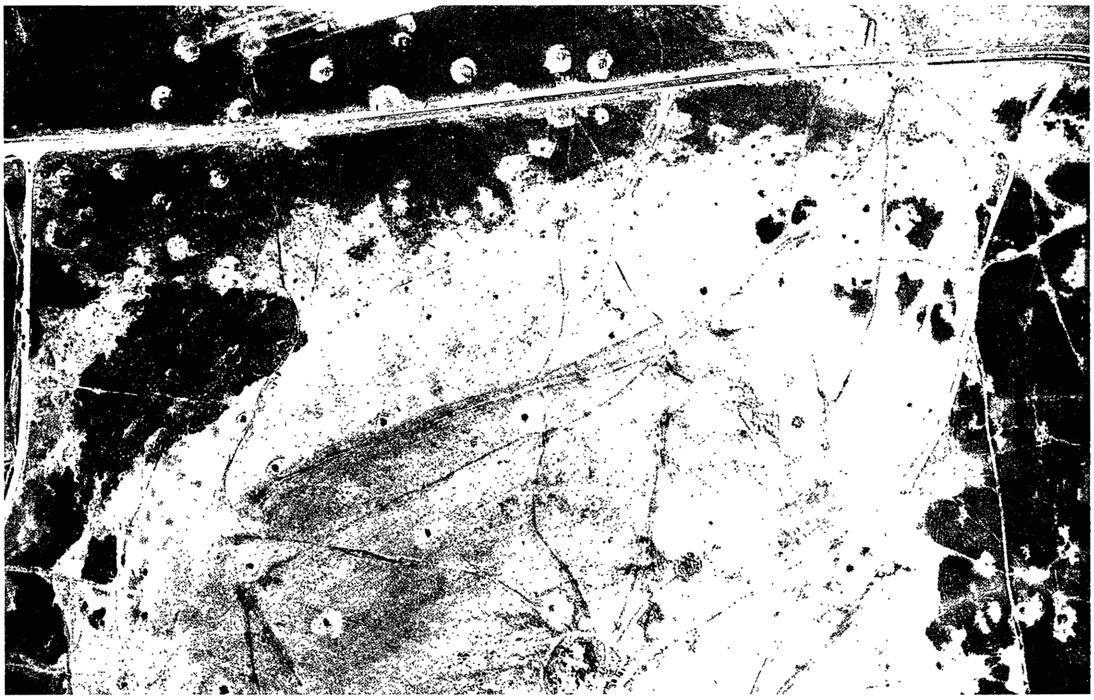


Plate 11 Aerial photograph showing location of bell pits at Baildon Moor, surrounded by low mounds of colliery spoil (reproduced with permission of City of Bradford Metropolitan Council, Transportation and Planning Division.

mines in the District during the peak years of coal extraction, during the 19th Century, as it permitted greater productivity associated with higher extraction rates of coal than by pillar-and-stall methods.

The peak of the coal industry in the area was reached in 1866, when 1.9 million tons of coal were produced from Bradford's 46 collieries, representing 20% of West Yorkshire's total output (Richardson, 1976). At this time, nearly half of these remaining collieries were owned by the Low Moor and Bowling Iron Companies. Consequently, the industry had largely seen a contraction in coals worked to the Better Bed and Black Bed, present only in the south-east of the District. The Better Bed, with high carbon content and low contents of impurites, such as sulphur, was used in metal manufacture, whereas the poorer quality Black Bed, along with the overlying ironstone, could be worked for engine coal. By 1924 only three pits were still operating in Bradford (Richardson, 1976).

Sandstone Workings

Sandstone was mined locally, during the 19th and early 20th centuries, either from adits driven from the bottom of quarries, or from stone shafts. Details on the techniques employed by this type of mining are provided by Anon (1900), Godwin (1984), and Arup Geotechnics (1991; vol. 3/viii). The workings would have involved the driving of two orthogonal headings or drifts for about 45 m from the adit or shaft (Figure 16). One heading was often parallel to the strike of the sandstone beds, the other parallel with the dip. Two further cross headings were driven at right angles to the first set, thus forming a square. The stone was worked by the progressive widening of the cross

Plate 12 View of Dog and Gun Clay Pit [SE 053 344], the only working fireclay pit in the district, showing pillar-and-stall workings in the Hard Bed Coal, which overlies the worked fireclay.

Plate 12 View of Dog and Gun Clay Pit [SE 053 344], the only working fireclay pit in the district, showing pillar-and-stall workings in the Hard Bed Coal, which overlies the worked fireclay.

headings. The width of the drift was typically 4 m, though was dependent on jointing, and the height was slightly greater than the thickness of stone to be worked; typically 1.5 to 6 m. Sandstone mines are recorded to depths of about 40 m. A typical pattern of workings in a single sandstone mine is shown in Figure 15.

During stone extraction, the roof was temporarily supported by timbers, and subsequently by stone spoil, to form a judd-wall. When as much stone was worked as possible, the timber was removed. This method involved almost total extraction with no pillars of stone left, except adjacent to the shaft. However, where pillars are left to support the roof, the workings may remain open for considerable periods after cessation of working.

Underground sandstone workings are recorded at Idle Moor [SE 17 37], Shipley [SE 138 376], Allerton [SE 113 343], Lister Hills [SE 148 333] and Peel Park [SE 168 346]. Godwin (1984) provides a comprehensive list of sandstone mines, their location, the operators and age of the workings. The entrances to workings can still be seen at Ellcliffe Quarry [SE 1147 3473], leading to a large open cavity (Plate 13) and Black Dyke Quarry [SE 0885 3378]. At Peel Park, a complex system of shallow workings were discovered following the formation of a 17 m deep subsidence hollow in 1977 (Godwin, 1984) (Plate 14).

Mine entries

A great number of shafts and adits have been sunk in the Bradford District, both for coal, and related minerals, or for sandstone. The most comprehensive shaft database available is held by the Coal Authority, with this information summarised on Map 5, reproduced from a 1:25 000 scale plan. The location of many colliery shafts can be ascertained from old topographic maps, either directly by showing shaft positions or indirectly by showing circular mounds of colliery spoil (Plate 15). Sandstone shafts have been less comprehensively recorded, and the locations shown on Map 5 have been derived from topographic maps and the few available abandonment mine plans (e.g. Figure 16). No reliance can be made on the accuracy, completeness or reliability of the mine entry locations shown on Map 5. There are almost certainly old shafts and adits, not shown on the map, for which records were not made or have been lost and which remain to be discovered. ***The responsibility for locating and treating shafts at or close to development sites rests on the site owner or developer. Enquiries concerning the location of colliery-based mine shafts should be made to the Coal Authority.***

During the 17th Century fireclays were worked by shallow adits, or 'day holes', driven into the seam from the valley side. Such workings are recorded at Riddlesden [SE 065 462], Long Lee, Keighley [SE 086 405]. Similar day holes are recorded for working coal at Foreside [SE 0610 3215]. A number of adits present in valley sides may have been used for mine drainage; these are known locally as soughs.

Adits rarely exceed 3 m in diameter, though older examples are often little more than 1 m in diameter, and are rarely completely backfilled on abandonment (Culshaw and Waltham, 1987).

Early coal shafts, from the 17th Century, were typically no more than 1.5 m in diameter and reached depths of up to 25 m deep. These were unlined, except when passing through loose ground. Puddle clay would be used to keep out the ingress of water into the shaft. Later shafts would typically be stone, or more rarely brick-lined and have diameters of about 5 m. For each colliery, it was common practice to sink a number of shafts, including air shafts to improve ventilation, pumping shafts for mine drainage and engine shafts to improve transport of coal from the face to the surface. Some confusion may result from the use of 'air shaft' on old topographic maps, as this term may also be used for ventilation of railway tunnels or water conduits. A number of shafts shown on the British Coal plot of mine entries includes air shafts related to such non-coal related excavations.

Sandstone shafts were typically 3.0 to 5.0 m in diameter and commonly sunk to a depth of up to 30 m, though at Idle a shaft of 45 m is recorded, with shafts commonly spaced from 50 to 90 m apart (Godwin, 1984). The shaft was usually partly or wholly filled with spoil on abandonment.

Figure 16 Mining methods formerly used to extract coal, fireclay, ironstone and sandstone (after Littlejohn, 1979; Healy and Head, 1984; Arup Geotechnics, 1990); a) bell pits, b) pillar-and-stall workings, c) longwall workings, d) sandstone workings.

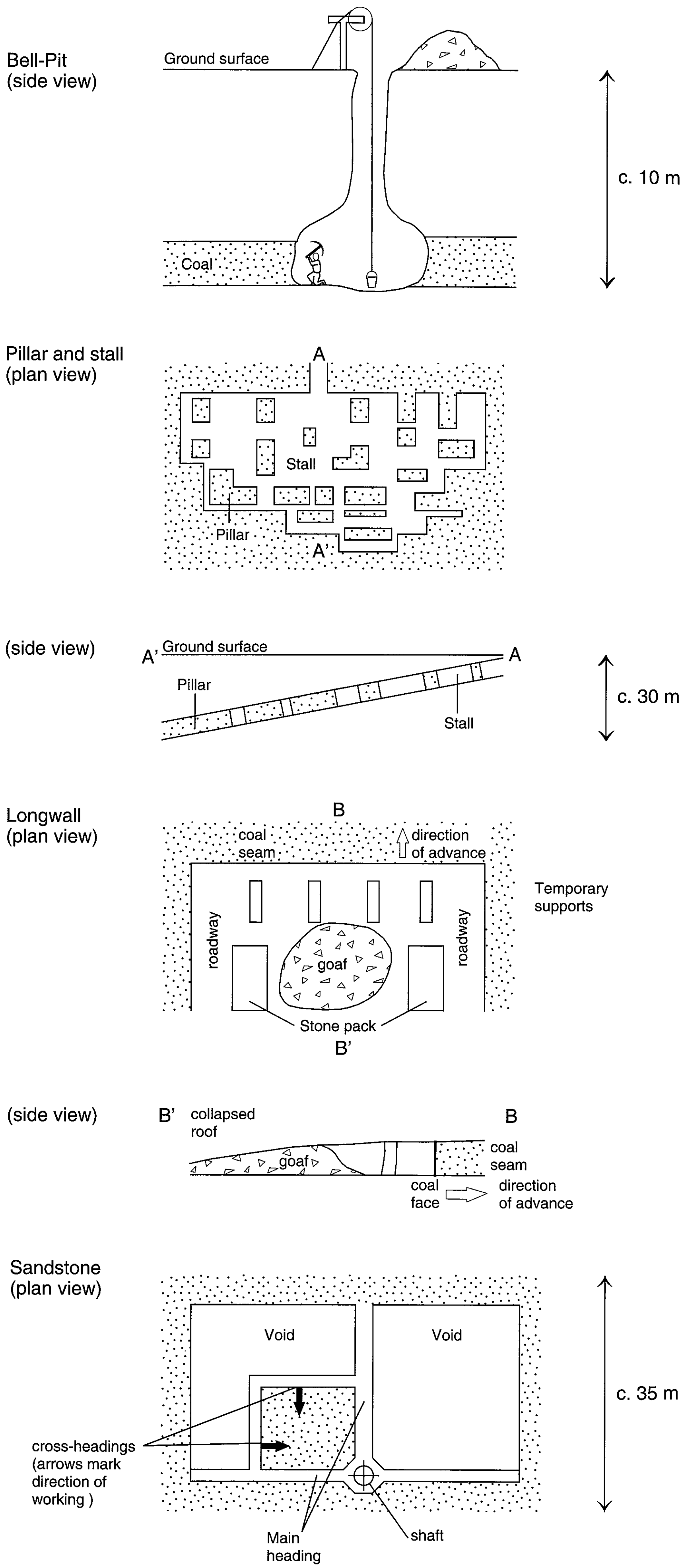
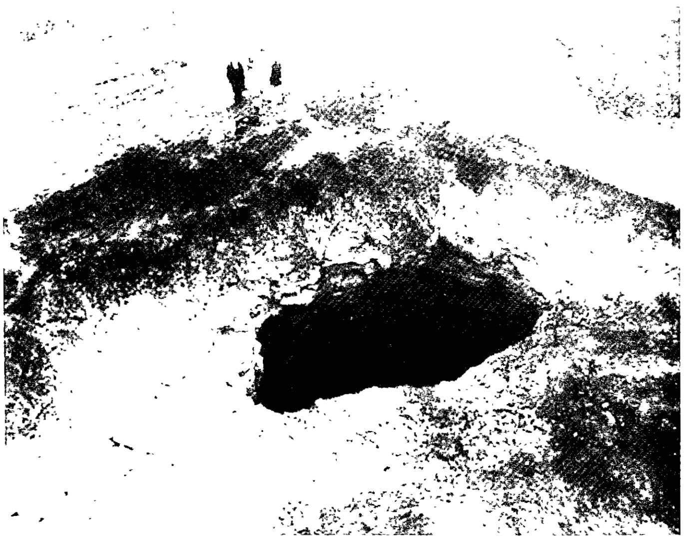


Plate 13
Underground sandstone workings at Ellcliffe Quarry [SE 114 348]; open void in the Elland Flags.

Plate 13 Underground sandstone workings at Ellcliffe Quarry [SE 114 348]; open void in the Elland Flags.

Plate 14 Collapsed underground sandstone workings at Peel Park [SE 167 348], published with permission of City of Bradford Metropolitan Council, Design and Construction Services.



Mining subsidence

The coal seams which lie below Bradford at shallow depths are known to have been worked extensively and a number of buildings have historically suffered cracking, settlement or damage requiring repair or demolition. In many cases, this reflects historical construction without prior site treatment.

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 are described by Culshaw and Waltham (1987). An approach to the strategy for making the engineering decisions on treatment when building in areas of shallow mines is described by Cole (1987).

Bell pits

In many cases the bell pits were only partly backfilled and the present state of compaction is almost certainly very variable. The fill materials usually consist of silty clay and moderately to completely weathered mudstone fragments with traces of coal and/or ironstone nodules. Rotting timbers are sometimes encountered.

Pillar-and-Stall Workings

Ancient mining by partial extraction was usually at rela-

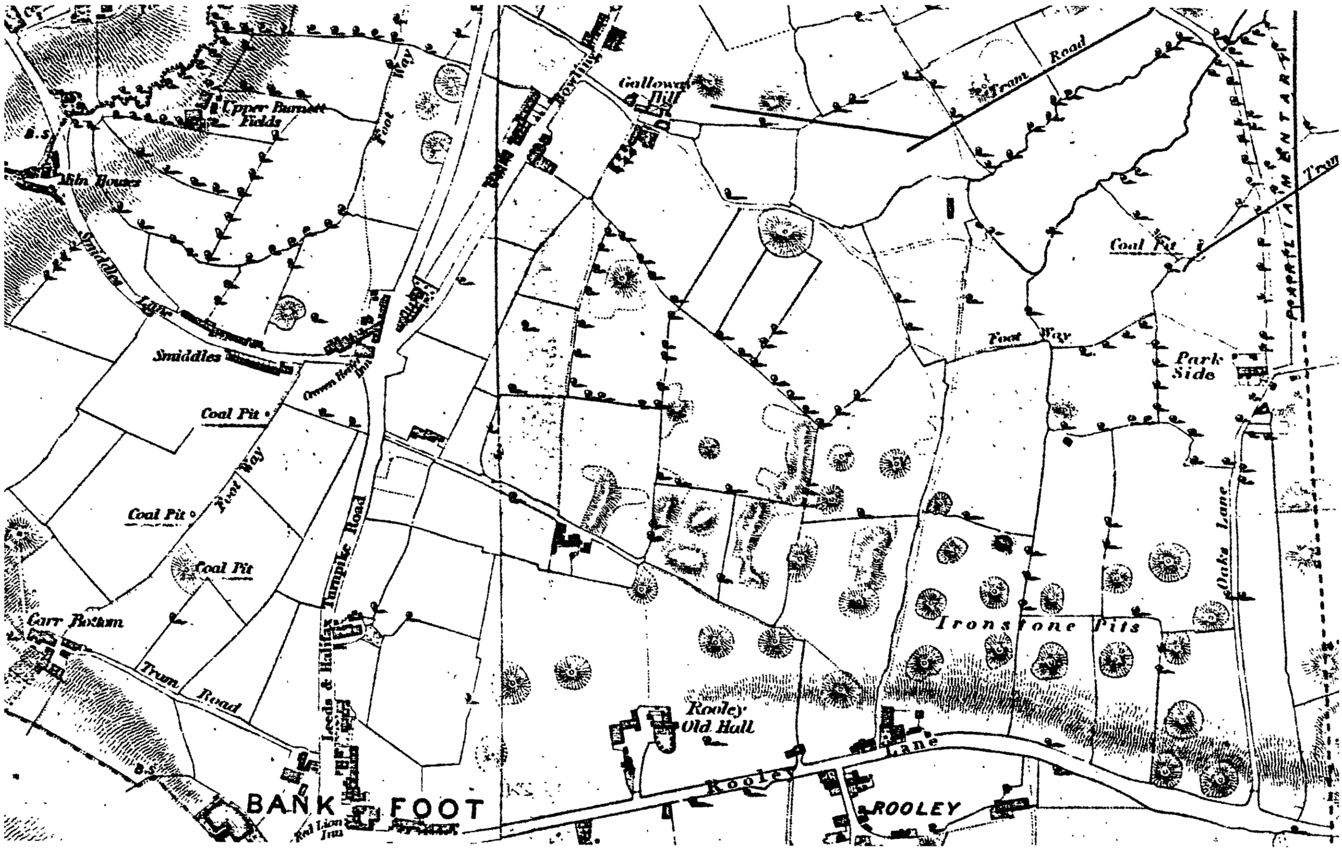


Plate 15 Example of a topographic map, dated 1846, showing the location of ironstone and coal pit shafts and spoil mounds.

tively 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 within 30 m of rockhead. As drift thicknesses over most of area of underground colliery workings are less than 5 m (compare Figures 10 and 14), this approximately equates to the area shown on Map 5, which shows workings at up to 30 m below the present day ground surface. Such shallow workings may cause serious problems for new construction work and are a common cause of structural damage in the Bradford area. Three principal mechanisms of failure of shallow mine workings, shown on Figure 17, may be considered (Pigott and Eynon, 1978):

a) squeeze of floor or roof strata
b) pillar failure
c) collapse of roof beds spanning adjacent pillars

Mechanism (a) is a relatively short-term effect unless influenced by changes in groundwater conditions.

Mechanism (b), collapse of pillars, is comparatively rare unless the pillars were of insufficient size during initial coal extraction or were subsequently 'robbed'. Pillar collapse may result from deterioration due to weathering, but is a rare occurrence. Also, material from roof collapses provides lateral restraint which tends to enhance the strength of the pillars by 'buttressing'. Pillar collapse can be precipitated by longwall mining below old workings, but as much of the Bradford area lies within the abandoned coalfield, it is unlikely that further deep mining will occur. Pillar failure is more common at depths greater than about 30 m to 50 m, where the uniaxial compressive strength of the coal is exceeded by the pressure of overburden. However, as most of the workings are over 100 years old, pillar failure leading to surface settlements will have ceased in all but a few cases.

Mechanism (c) is a major cause of ground instability problems as the collapse of roof beds spanning adjacent pillars may lead to upward propagation (migration) of a void. This can occur within a few months, or a long period of years after mining has ceased. When void migration occurs, the material involved in the fall 'bulks', which means that the migration is eventually arrested, but the bulked material never completely fills the void (Figure 17). At shallow depth, void migration may continue upwards to the ground surface leading to the possible formation of a crown hole (Figure 17). Pigott and Eynon (1978) and Bell (1980) showed that the maximum height of the zone of collapse is commonly up to 6 times the height of the mine void but may, exceptionally, exceed tenfold (Littlejohn, 1979). Following collapse of roof strata, the depth from which a void will migrate to the surface to form a crown hole varies with the geometry of the workings and the nature and condition of the overlying strata.

Pillar-and-stall workings with low extraction rates, or with a thick, high strength overlying sandstone, or which were fully back stowed are less likely to result in ground surface deformation.

Longwall Mining

Subsidence from longwall mining is usually rapid (within days of extraction) and residual subsidence is typically completed within 2 years of the cessation of coal extraction. Maximum subsidence by an amount up to 80% of the

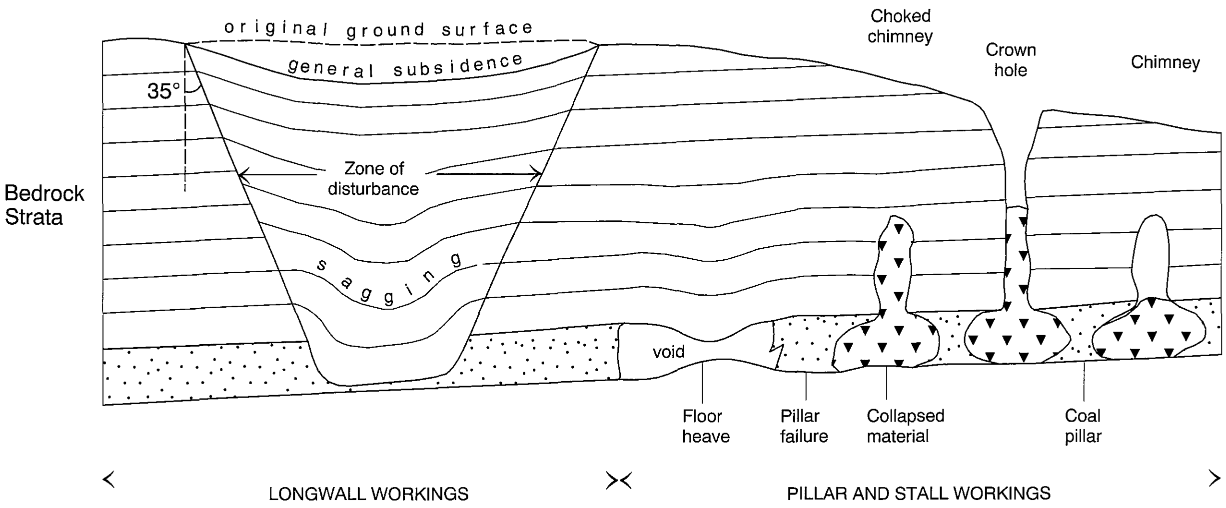


Figure 17 Schematic cross-section showing the types of subsidence associated with coal mining methods.

original seam thickness, occurs when the width of the panel exceeds 1.4 times the depth of the seam (Healy and Head, 1984). Subsidence at the surface includes a peripheral area of influence (Figure 17), usually defined for coal seams with a low dip, by projecting an 'angle of draw' of approximately 350 to the vertical from the periphery of the workings at the worked level to the ground surface (Whittaker and Reddish, 1989). In the Bradford area, the subsidence associated with total extraction has finished, leaving a resultant lowered ground surface (Figure 17). No further mining is likely and most of the past longwall mining took place at considerable depth in relation to typical foundation levels. In most areas, therefore, the presence of past longwall mining beneath a site is unlikely to compromise the integrity of future structures.

Access roadways which had to remain stable for long periods during the life of the mine were commonly well supported by iron, stonework or brickwork because. 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. A further problem is associated with the stowed waste, or 'goaf', which is much weaker than the natural adjacent strata and heavy structures which stress the goaf may experience larger than anticipated settlements.

The process of longwall mining may result in fracturing and disruption of the bedrock. Of particular importance is the reactivation of faults by undermining, which 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 12).

Stone workings

The main risk associated with underground sandstone mines is the potential of ground surface subsidence due to the collapse of open voids. In general, the thickness of stone removed was greater than that for coal and the cavities were rarely completely backfilled after working ceased. Crushing of supports, such as wooden props or judd-walls, or crushing of pillars, roof collapse or floor heave result in the filling of the void with time. The greatest hazard is the sudden and unpredictable collapse of the roof, which may result in the upward migration of the void as a chimney shaped conduit, until the surface is reached and a crown-hole develops. Recent evidence of subsidence of stone mines in the District includes the development of crown holes at Peel Park [SE 167 348] (Godwin, 1984) in 1977, which occurred following storage of topsoil in the area, with a resultant increase in overburden pressures. The crown hole was 1.2 by 0.6 m in diameter and 17 m deep (Plate 14). The collapse of the roof of a sandstone heading at Fall Top, Clayton [SE 113 315] in 1993, produced a crown hole about 0.6 m by 0.4 m in diameter, and 9 m deep, adjacent to housing.

Mine entries

Mine shafts may have been only partially filled, a poor state of compaction nearly always exists in the highly variable fill materials and voids are common. In the past, the fill may have been placed on a platform of girders or wooden beams, commonly located at rockhead, which may deteriorate and collapse with time. Even when a mine or well shaft has been capped within the last 40 to 50 years, voids may not have been filled and old caps may be in a poor condition. Only shafts treated since 1982 may be assumed to have been capped to standards issued at that time by the National Coal Board (1982).

Collapse of shaft caps over empty shafts, collapse of the shaft fill leaving a void, and collapse of shaft linings into a void resulting in surrounding superficial deposits being drawn into the shaft are all potential threats to structural development. The latter may result in an area of collapse at the ground surface which is more extensive than the mine entry itself. Building over shafts can result in severe differential settlement problems and, at worst, catastrophic ground failure is possible without warning, with risk of injury or death.

The collapse of a disused mine shaft in 1979 resulted in subsidence in the central reservation of the M606 motorway, to the north of Oakenshaw [SE 17 29]. The subsidence was attributed to a change in the nature of the shaft fill resulting from the seepage of water into the shaft from the central reservation drain. A possible sandstone shaft partially collapsed at Idle Moor [SE 168 373] in 1976, producing a depression about 5 m deep and 6.5 m in diameter (Arup Geotechnics, 1991; vol 3/viii).

In addition to adverse settlement characteristics, old shafts may also provide potential problems as pathways for noxious or explosive gases, or polluted groundwater (see Chapter 12).

Other types of shafts, including water boreholes and wells, railway tunnel ventilation shafts and water conduit shafts may pose similar threats to surface development as those discussed for mine entries. The location of many of these shafts are shown on old topographical maps.

Summary and recommendations

The District has had a long history of underground mining for coal, fireclay, ironstone and sandstone. Despite the absence of active mining for these minerals, the presence of old abandoned workings at shallow depths and mine entries represents a potential hazard to development in parts of the District.

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: Freeman Fox (1988), PPG 14 (Department of the Environment, 1990), and Arup Geotechnics (1992). Additional guidance is given by Healy and Head (1984) and BS 5930: 1981a.

The following recommendations relate to the location, monitoring and treatment of areas affected by different mining methods or by the presence of mine entries.

Areas associated with old mine workings

1. Location of the hazard

It is essential that in an area of known, or possible underground mining, that a detailed and thorough site investigation is carried out by suitably qualified professionals. The aims of such a site investigation should be to identify the hazard, to gather information which will assist in the siting of structures, to aid the design of ground improvement works and the design of foundations. The site investigation should have the following objectives (from Forster et al., 1995):

a) establish whether or not mining has taken place beneath the site,
b) determine the geometry of the workings,
c) determine the condition of the workings,
d) establish the sequence of overlying strata,
e) determine the engineering behaviour of the strata,
f) determine the geotechnical properties of the materials present.

Methods employed for the investigation of old mine workings and shafts are well documented (Arup Geotechnics, 1991; 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 site investigation should take into account plans of old workings which may indicate the spacing and dimensions of likely pillar lay outs. However, even where plans do exist they may contain inaccuracies within the workings, and may be difficult to locate relative to present day topography. In certain circumstances, aerial photographs may provide information on the pattern of shallow workings (Giles, 1987).

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 pillar-and-stall workings showing little sign of collapse. It is therefore 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.

In those areas where longwall mining occurred at relatively shallow levels (less than about 50 m below ground surface), site investigation techniques should be the same as for those suggested for pillar-and-stall workings. However, where the stowed waste ('goaf') is well compacted, it may be difficult to recognise the workings by rotary open hole boring. In such cases it will be necessary to selectively 'spot' core (i.e. openholing to an estimated 1 to 3 m above the suspected level of the workings, followed by core drilling until the workings are fully penetrated).

Once workings have been found, monitoring can be used to indicate possible impending surface subsidence. Various methods of monitoring can be employed, with appropriate techniques differing in individual mines. The methods, reviewed by Arup Geotechnics (1991; vol.2/iv) include visual inspection, close circuit television cameras, strain guages, microseismics, acoustic emissions. An example of the use of remotely controlled borehole cameras in the monitoring of old coal mine cavities in Bradford is provided by Anon. (1970).

2. Treatment of hazard

Once the old workings are identified and their extent and depth established, a number of options are available for site development and construction. These are reviewed by Healy and Head (1984), Arup Geotechnics (1992), Bell (1978, 1987) and Waltham (1990).

It is important that the design of necessary preventative or remedial works are carried out by suitably qualified professionals and that treatment is carried out by specialist contractors.

In areas of known shallow workings in which development of surface crown-holes is a serious risk, it may be advisable to avoid building over the affected area. In large parts of Bradford, considered to be within the area affected by shallow mining, the prevention of development is not an adequate solution. For such areas there are a number of preventative or remedial techniques which may be employed before and after, respectively, any problem has developed. These are summarised in Table 13, and described in more detail by Arup Geotechnics (1991).

Bulk excavation and fill may be viable in areas where large amounts of coal remain unworked, though there are practical limitations to the depth and areal extent of excavation for a site to be feasible. Induced subsidence by the demolition of pillars and resultant collapse of the roof may be viable in areas of high coal extraction rates (greater than 75%) and in areas of sandstone workings, which generally have few supporting pillars. However, the potential damage of onsite or nearby developments or services is a problem with this technique.

Design of special foundations and modification of structures are often the most suitable form of prevention of structural damage, especially where other remedial measures are not feasible. Further information of foundation engineering is provided by Bell (1978), Building Research Establishment (1983b) and National House Building Council (1995).

Mine stabilisation, particular for sandstone workings, may be achieved by strengthening mine pillars and the installation of additional support. However, this requires access to the mine, which may have no entrance, is likely to be unstable and may be flooded. The sandstone workings at Peel Park [SE 167 348] were treated by backfilling of the collapsed area with 80 tonnes of stone, covered with 825 tonnes of quarry waste, in turn covered with ash, building materials and waste road covering, which were rolled into place (Arup Geotechnics, 1991; vol. 3/viii).

The grouting of old workings, including pillar-and-stall workings, sandstone workings and open roadways from longwall mines, or migrating voids is often a relatively simple and successful solution. The guideline specifications are provided by Healy and Head (1984). A drawback is that if groundwater is flowing through the workings, it may be dammed by the grout and result in an increase in the head of water, high pore pressures, uplift forces and erosion.

Ground anchors may be used to provide temporary or permanent support to bedrock present above mineworkings. The advantage of this technique is that it provides roof stabilization without requiring entry into the mine. Information on the design of ground anchors is provided by British Standard 8081 (1989).

Areas associated with mine entries

1. Location of hazard

The following methods may be employed to investigate shafts and old workings. A combination of several methods used in conjunction may prove more successful than a single method or methods used in isolation. A review of procedures for locating disused mine entries is provided by the Review of Mining Instability in Great Britain (Arup Geotechnics, 1991; vol 2/v):

a) The first stage should be a comprehensive search through archival material, which should include Ordnance Survey maps, which may show the location of pits or colliery spoil mounds (Plate 15), British Geological Survey geological maps and field maps, and the Review of Mining Instability (Arup Geotechnics, 1991). Abandonment mineplans, held by the Coal Authority for colliery-based mines, often provide important information on mine entry locations. However, such mineplans were only legally required to be produced on mines abandoned after 1852 and the requirement that these should be retained did not come into force until the 1872 Act. Many of the shafts in the District are much older and are unrecorded. Even where mineplans exist, the position of the shafts may be inaccurate or difficult to relate to a topographic base. Aerial photographs can identify anomalous tonal or topographic features indicative of old shafts and pits. An excellent example of the use of aerial photographs is the identification of numerous shafts on Baildon Moor (Plate 10), most of which were unrecorded on maps or mineplans.

b) The second stage of site investigation should include a field reconnaissance. Important techniques include:

i) A site walkover to look for the remains of shafts, such as headworks, spoil mounds and subsidence hollows.

ii) 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, microgravity, magnetic, seismic tomography, and ground probing radar. The choice of methods employed will vary from site to site.

iii) Geochemical surveys, particularly for soil-air methane, may indicate the location of gas emissions from shafts.

The above techniques permit a wide area of investigation with little or no disturbance of the ground. However, they provide only guides as to the likely position of shafts, and site investigation techniques are required to conclusively prove shafts.

c) The final stage of a site investigation should be field investigation:

i) Excavation is the most satisfactory method for proving the position of shafts (Arup Geotechnics, 1991; vol. 2v). Trenches, pitting and soil stripping may be useful methods in themselves or to investigate targets identified by other means. Trenches should be excavated in strips, with an appropriate spacing relative to the anticipated diameter of the shafts.

ii) When a site cannot be disturbed by excavation, it is advisable to use boreholes arranged in a specific drilling pattern about the best shaft location identified

Table 13 Preventative and remedial techniques for areas prone to mining subsidence (after Arup Geotechnics, 1992).

Method	Technique
Bulk excavation and fill	Excavate and replace ground with compaction
Induced subsidence	Dynamic compaction Dewatering Water or gas injection Explosive fracturing
Special foundations	Strip and pad foundations Raft foundations Grillage foundations (ground bearing beams) Piled foundations
Modified structures	Flexible structures Linear structures and services Basements Retaining walls Reinforced soil Gaps and joints Geotextiles
Treatment by entry into the mine	Pillar strengthening Roof support Rock reinforcement Stowing Protection from weathering
Treatment from boreholes	Granular infilling Grouting Rock paste injection
Treatment from the surface	Ground anchors

from other methods (see above). Once a shaft is 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.

2. Treatment of hazard

Building over or close to shafts should be avoided, whenever possible, even though some structures have existed over such sites for centuries without damage. In all cases, appropriate professional advice should be sought for shaft treatment and development in areas where disused mine entries may present a hazard. It is essential that desk top assessment and site investigations are employed to determine the condition of shafts and their filling/capping and design appropriate solutions prior to development. The treatment of every shaft should be considered on an individual basis. Guidelines for the treatment of disused mineshafts is provided in a report by the National Coal Board (1982) and Freeman Fox (1988).

a) In bell pits, grouting may be unsuccessful in the ancient, generally cohesive backfill. If cost-effective, it may, in some cases, be worthwhile to opencast sites occupied by bell pits. Foundations can then be placed on underlying rock, or on overburden following its replacement in well-compacted layers.

b) Shaft voids can be filled by the introduction of pea gravel. However, consideration should be made of the possibility of sparking by a gravel with high quartz content, which could result in the ignition of methane. Furthermore, the pea gravel may be washed away in shafts affected by strong flows of water. This can be overcome by the introduction of a grout, though the possibility of adverse affects on mine drainage should be considered.

c) In an urban area, shafts usually have 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.

9 Slope stability

Introduction

Evidence of slope instability due to landslips, or landslides, is widespread in the District and details of 201 individual landslips or landslip areas are recorded in the landslip database which accompanies Volume 2 of this report. If development pressures, particularly for housing and improved infrastructure, lead to building on ever steeper slopes, the possibility of encountering slope stability problems associated with existing landslipped ground, or that susceptible to future movement, is likely to increase. However, if proper ground investigations are undertaken on unstable, or potentially unstable, ground and suitable preventative or remedial measures are employed, the majority of problems may be overcome. The occurrence and distribution of existing landslips is a principal pointer to those areas where future slope movements may occur. The types and development of these features in the Bradford District are discussed below.

Landslip types

Landslips are the downslope mass movement of soil and/or rock under the influence of gravity. Movement may be slow or very rapid; it may be continuous or subject to intermittent surges. The scale of movement also varies and landslips in the District range from those affecting a few square metres to large failures involving several hectares.

The most commonly used classification scheme to describe the various types of landslips which can develop is based on that of Varnes (1978). This scheme, used here and adopted in PPG 14 (1990), is reproduced with minor modification in Figure 18. It is essentially based on the type of movement, ie. the mode of failure, involving consideration of the initial rupture surface; the dominant form of displacement and the subsequent behaviour of the material as it deforms after initial movement has commenced; and the material involved in the movement. The dominant forms of displacement are:

Falls — abrupt movement of material detached from a steep slope or cliff, usually from joints or fissures, with little or no shearing; most of the movement is through the air as free-fall, rolling or bouncing; initial detachment may be by sliding or toppling.

Slides — material moves by sliding movement along a recognisable shear surface (or surfaces) which may be circular or near circular (rotational slides) or essentially planar (translational slides).

Flows — slow to very rapid mass movements of saturated materials which advance over the land surface as a viscous fluid with movements between grains predominating over shear surface movements; initial displacements are usually by sliding which rapidly transforms to flow.

Complex — Combinations of two or more of the above movement types.

The importance of ground material in the classification is recognised by further subdivision based on:

rock — i.e. bedrock;
debris — coarse-grained engineering soils dominated by materials of gravel-size or greater, including admixtures of boulders;
earth — fine-grained engineering soils dominated by clay to sand-size fractions.

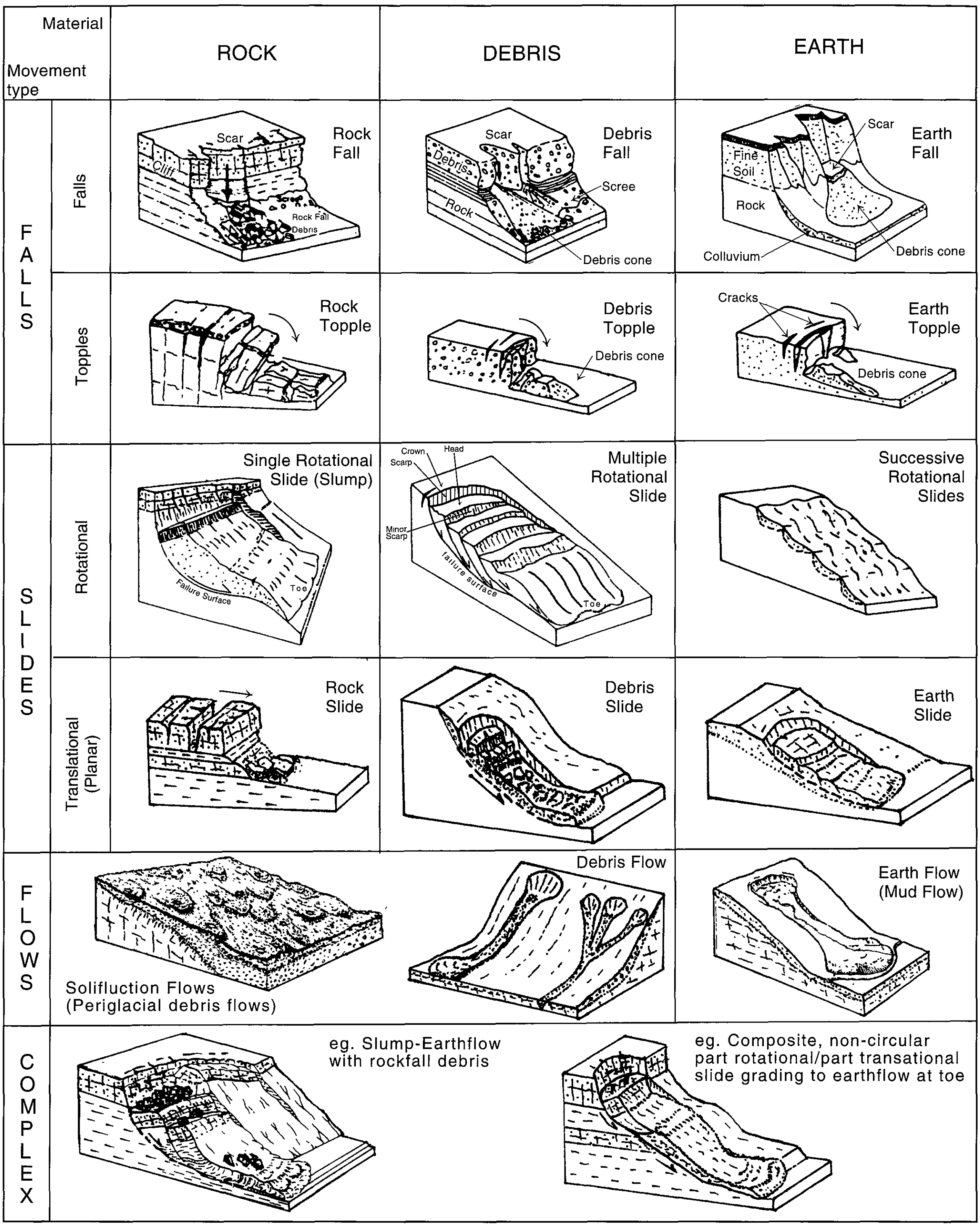
The majority of landslips in the District are relatively shallow rotational and translational earth and debris slides in Till and/or weathered materials (including Head deposits) mantling the hillslopes. Rotational slides (Plate 16) occur most frequently in relatively uniform clay Till (boulder clay) where thicknesses are generally more than c.3 m. Many of these slides show more than one phase of failure movement with multiple rotational slides frequently developed in the thicker Till sequences. Where the Till is thin or dominantly clayey weathered slope mantles are present, very shallow successive rotational slides, often forming a step-like or mozaic pattern across the slope, are not uncommon. Translational slides are mainly developed in the weathered, more granular debris mantles with planar slip surfaces usually running sub-parallel to the slope at a depth generally at, or very close to, the boundary of less weathered rockhead. In reality, the great majority of landslips are complex, showing evidence of both translational and rotational elements with subordinate flow. Flows rarely occur as individual features but are usually developed, to a greater or lesser degree, at the foot of both translational and rotational slides to form earth or debris flow 'aprons' at the slide toes.

Virtually all of the larger landslips in the District are complex, showing evidence of both slide and flow movements and, where the slides are formed below steep sandstone backscarps, extensive accumulations of rockfall detritus (Plates 2 and 17). These slides are often characterised by a highly irregular topography and are representative of a multiplicity of slope movement phases and types rather than single events. The steep slopes and irregular topography associated with these landslips, and also smaller multiple rotational slides, promotes ponding of water from springs, seeps and surface runoff. In combination, these factors tend to maintain such landslips in a state of marginal stability.

In many cases, landslips in the District are ancient, degraded and vegetated features which, in some areas, have been further modified by human activity related to quarrying, shallow mining and built development. Such landslips are almost impossible to classify from a brief walkover survey and without recourse to subsurface investigation. For the same reason it should not be assumed that all the landslips in the District have been identified during the present geological resurvey.

Causes and distribution of landslips

The distribution of landslip deposits in relation to the solid, superficial and engineering geology is presented on Maps 2, 3, and 7, and summarised on Figure 19 (*see* rear of book). On



Falls - Mass detached from steep slope/cliff along surface with little or no shear displacement, descends mostly through the air by free fall, bouncing or rolling; Topples - forward rotation about a pivot point; Rotational slides - sliding outwards on one or more concave-upward failure surfaces; Translational (planar) slides - sliding on a planar failure surface running more or less parallel to the slope; Flows - slow to rapid mass movements in saturated materials which advance by viscous flow, usually following initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but the dominant movement of the displaced mass is by flowage; Complex slides - slides involving two or more of the main movement types in combination.

Figure 18 Classification of type of landslip (after Varnes, 1978 and PPG14: 1990, with modifications).

Plate 16
Example of a shallow rotational slide at East Morton.

Plate 17
Example of a topple rock fall at the Cow and Calf Rock. The site is also an important conservation and recreation site.

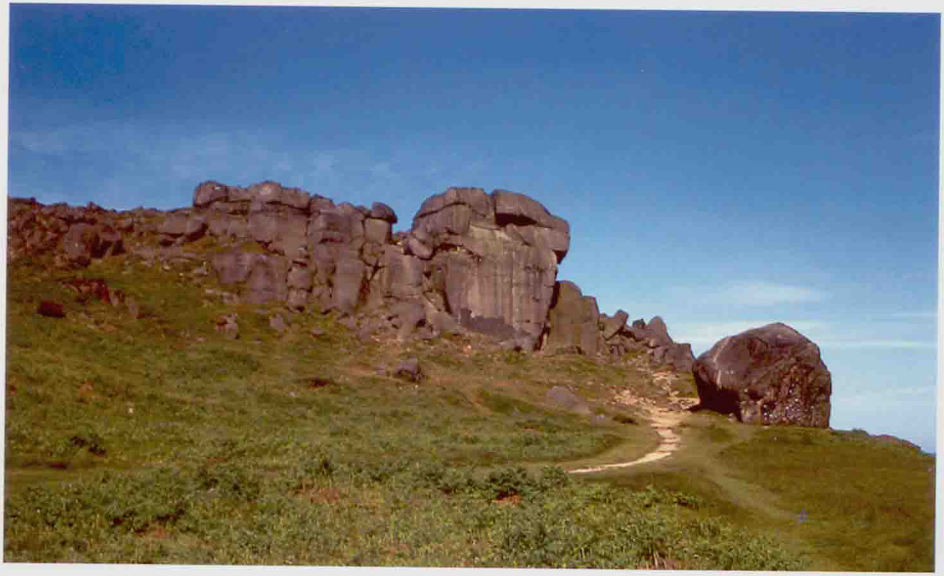


Plate 16
Example of a shallow rotational slide at East Morton.

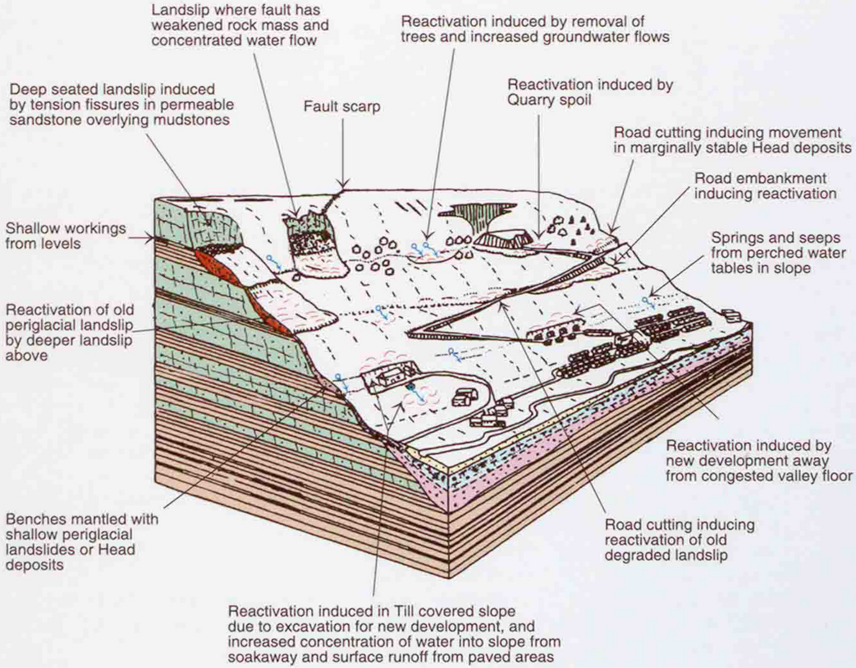
Plate 17
Example of a topple rock fall at the Cow and Calf Rock. The site is also an important conservation and recreation site.

Map 6, landslip distribution is shown in relation to zones of slope steepness. The mapped distributions indicate that many of the landslips are located on the steep north-facing slopes of the Aire and Wharfe valleys, particularly between Keighley and Bingley and in the vicinity of Ilkley. Landslips are also common in a number of small tributary valleys, including the Worth Valley, Newsholme Dean, around Silsden Reservoir and adjacent to Bradup Beck.

The distribution and significance of these landslips is affected by a number of inter-related factors including bedrock and superficial geology, depth of weathering, relief, climate (especially rainfall), hydrogeological conditions, geomorphological processes and human activity. Many of the landslips in the District initially developed in response to conditions much different to those of the present day. In particular, after the last glaciation, about 10 000 years ago, many landslips formed as a result of downslope movements in saturated, deeply weathered, partially frozen materials on the glacially over-steepened slopes. As the climate ameliorated, these landslips gradually became dormant. In consequence, a legacy of ancient landslips exists, often concealed under ground that has become degraded and vegetated or superficially remodelled by later events. Whilst the evidence of these earlier movements can often still be seen, some of them have very subdued surface expressions. Under present conditions such areas may remain dormant unless the factors controlling stability are disturbed by natural processes or by human interference.

Detailed assessment is necessary to ascertain the factors controlling hillslope stability at specific locations as they

Figure 20
Some influences on the occurrence and distribution of landslides in the Bradford District (based on Halcrow, 1993, with minor modification).



can vary considerably from site to site. However, the following factors, acting in various combinations, are significant:

- natural slopes with angles ranging from 11–18°; larger landslips involving weathered bedrock tend to develop on slopes in excess of c.20°.

- slopes with a thick cover of glacial Till and/or a mantle of deeply weathered mudstone material.

- the presence of a jointed, permeable, water-bearing capping of sandstone overlying a relatively impermeable mudstone, which maintains steep slope angles and promotes spring and seeps at the sandstone/mudstone interface.

- the presence of a fault, or faults, associated with weakened, fractured or deeply weathered strata and/or steeply inclined bedding dips and springs or seeps.

- hillslope springs and seeps associated with perched water tables arising from permeability contrasts within the bedrock and at the upslope margins of impermeable clay Till.

Movement occurs when the forces contributing to movement (i.e. loading forces) exceed those resisting movement (i.e. shear strength of material) and can be triggered by changes in the factors controlling these forces, either individually or in combination. Once movement has occurred the resisting strength is reduced to, or near, residual values and further movement (e.g. reactivation of ancient landslips) becomes more likely if there is any change in conditions. Changes brought about by natural processes which can initiate slope instability, or reactivate existing landslips, may include the removal of support from the foot of the slope by river erosion or heavy rainfall, which can increase weight and reduce effective strength by increasing pore pressures. Adverse changes due to human influences are numerous and include:

- top-loading of the slope by the placing of fills and other superimposed loads for construction purposes or the disposal of wastes.

- removal of support by excavation, for example by cuttings associated with road construction or benching for housing.

- introduction of increased volumes of water into the slope such as may occur due to diversion or alteration of natural drainage patterns during development; leakage of water-retaining structures, pipelines or sewers; and the uncontrolled disposal of water from soakaways or

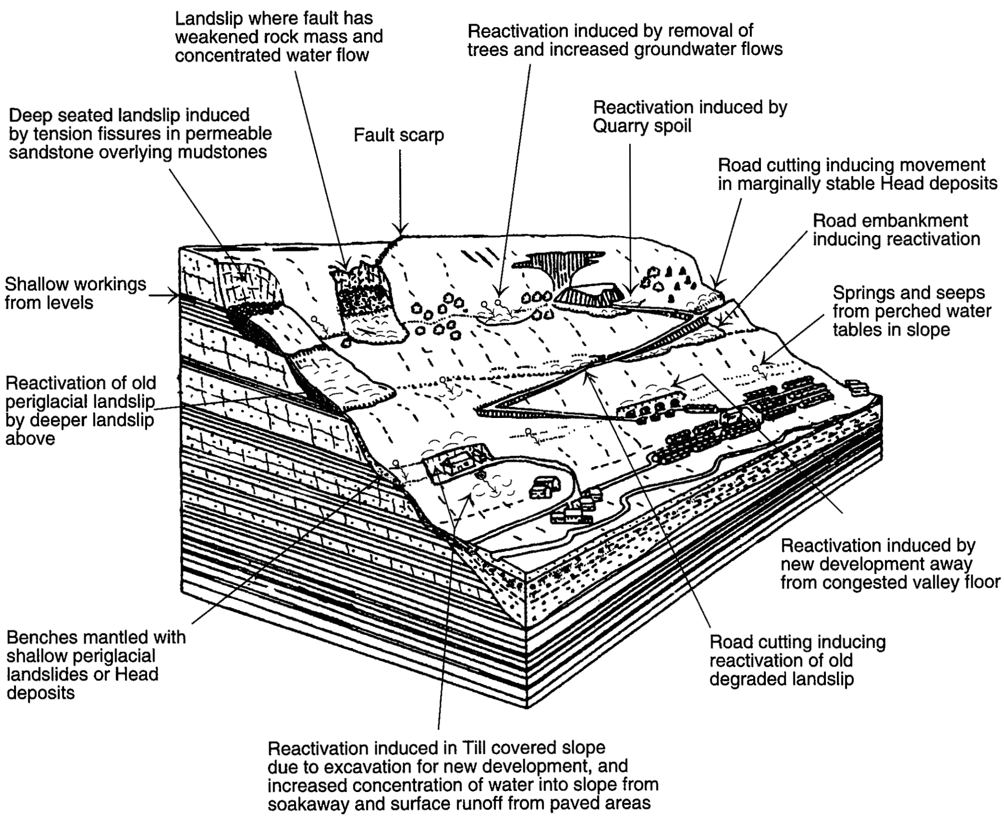


Figure 20
Some influences on the occurrence and distribution of landslides in the Bradford District (based on Halcrow, 1993, with minor modification).

A range of natural and human influences on the occurrence and distribution of landslips in the District is shown in Figure 20.

Summary and recommendations

The bedrock and superficial deposits, geological structure, glacial history, relief and high rainfall produce conditions susceptible to landslipping in many parts of the District. A legacy of ancient landslips exist, many of which have subdued, degraded or modified features which makes them difficult to recognise and delineate. The widespread distribution of landslip deposits, particularly on steep north-facing slopes of the Aire and Wharfe valleys and their tributaries, are indicative of areas of past instability and are useful pointers to those areas most likely to pose stability problems to future development. Other areas, previously unaffected by landslipping may become unstable if one or more the factors controlling present stability are adversely affected by natural processes or human interference. Evidence of current activity associated with nearly 40 landslides mapped during the geological resurvey points to the marginal stability of many slopes in the District.

Recommendations for development in landslip areas

Recognition

The most effective strategy for dealing with unstable, or potentially unstable, ground hinges on recognition of problem areas in advance of development. Avoidance or pre-emptive works will usually be less traumatic and costly than remedial works after movement has occurred. Landslips with distinct or 'fresh' morphological features which have not been excessively degraded or modified by weathering, erosion or human interference can usually be easily recognised by a competent engineering geologist, engineering geomorphologist or geotechnical engineer. Recognition of degraded ancient landslides can be more difficult but can be enhanced significantly by stereoscopic examination of aerial photography, by a skilled operator, in conjunction with reconnaissance field surveys. The use of aerial photography, at scales of 1:10 000 or larger, is therefore highly recommended for identification and boundary delineation of all landslides.

Preliminary assessment of slope instability at proposed development sites by a desk study of available information and 'walkover' inspections should be carried out at the earliest possible stage, and prior to planning site investigations. Engineering geomorphological mapping of the site and its environs at scales appropriate to the proposed development or potential slope instability problem is also advisable, and should be standard practice at the feasibility stage of construction projects in areas of existing or potential landslipping. Preliminary field inspections and the preparation of geomorphological maps (1:10 000 scale or smaller) or plans (larger than 1:10 000 scale) serve to assess areas surrounding proposed development sites as to likely influences on the site environs from landslips on adjacent slopes, or the potential threat to neighbouring land should instability be triggered during construction at the proposed site. Preliminary inspections and mapping also enable greater precision, and hence cost effectiveness, in the design of the site investigation programme.

Site investigation

Following preliminary assessments, site investigations should be designed to establish the factors controlling stability and, where present, the dimensions of existing landslips. Investigation should not be restricted to the development site and should include surrounding areas where landslipping could threaten the development within its anticipated life, or where stability conditions at the site may impinge on adjacent land. It is essential that the investigation obtain sufficient data to perform valid stability analyses; including surveyed slope angles, type and depth of movement, position of basal and intra-slip shear surfaces or shear zones, the strength of the slope materials and the maximum water table or artesian pore water pressure conditions within the slope (monitored over a suitable period to allow for 'worst case' conditions). Material strengths, particularly residual strengths along shear surfaces, should ideally be carried out on high-quality 'undisturbed' samples, but specimens remoulded to a specific moisture content and bulk density may be required if undisturbed samples cannot be easily obtained. At shallow depths, careful sample recovery from trial pits is the best option, with borehole samples required at depths greater than about 5 m. The method of boring will depend on site conditions but cable tool percussion or rotary diamond drilling, using air or water flush, to produce cores may be employed. The extensive use of trial pits is strongly recommended for landslip investigations as a relatively cheap and effective way of examining large sections of the slope materials. In areas where the slope deposits contain hard cobbles or boulders, it may be necessary to carefully excavate deep trial pits to recover suitable samples for testing.

Past experience reveals that ground and groundwater conditions may vary unpredictably over relatively short distances and, consequently, conditions pertaining at one locality cannot be extrapolated to apparently similar sites nearby. Accurate assessment of stability may only be determined reliably from data obtained at individual sites. In some cases, particularly where existing development is present on, or is threatened by, landslip, long-term slope monitoring using surveyed targets, strain-indicators and piezometers may be required to ascertain the activity of the slope.

The costs of a comprehensive site investigation to establish stability parameters may be quite significant even for a relatively small landslip. On large schemes, expenditure may easily escalate unless the objectives of the work are strictly defined. For minor constructions (e.g. garages or small extensions) a full-scale investigation may not be practical. PPG 14, Annex 1 (1996), suggests this may be acceptable provided the site is not significantly disturbed. Such provisos should be confirmed only after inspection from a 'competent professional'.

Remedial measures

If development on ground proved to be unstable by site investigation cannot be avoided, it must be made stable by appropriate engineered remedial works prior to development. Such work is a specialist task and should be carried out under the supervision of a competent engineer. Depending on the type and scale of the problem a number of remedial options are available, the most common of which are presented in Figure 21.

These measures may include one or more of the following:

- Increasing soil strength (e.g. by total or partial excavation of landslip material and replacement with stronger material; most applicable to small slips, particularly in locations where the existing geometry must be maintained and complete excavation and

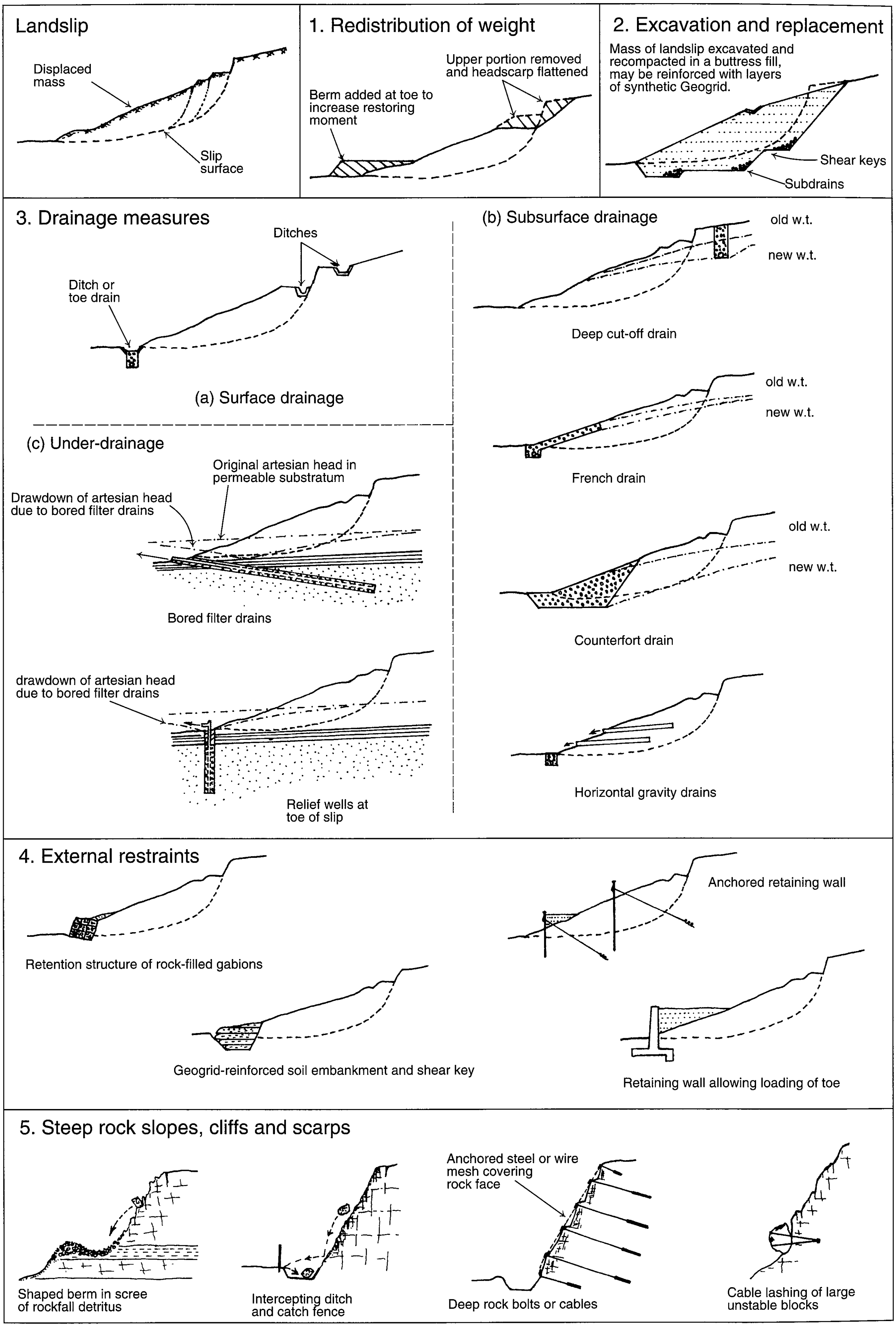


Figure 21 Some examples of slope stabilisation measures.

replacement with a free-draining granular material is both feasible and economical).

- Modifying the mass distribution (e.g. by adding weight at the toe in the form of a berm, by removing material at the crest, by reducing the overall height or flattening the slope, or a combination of these).

- Reduction of the pore pressures in the slope by drainage (e.g. surface water drainage, to prevent erosion and/or reduce infiltration; subsurface drains, to lower the water table where it occurs close to the surface; under-drainage, such as relief wells, bored filter drains, or drainage adits, where drainage of the strata at depth is required).

- External restraints (e.g. ground anchors, piles, counterforts or deep retaining walls keyed into undisturbed strata).

The selection of appropriate remedial works for specific sites may depend not only on geotechnical considerations but also on restraints placed on sites due to environmental, accessibility and existing development factors. However, of the remedial options available, that of drainage deserves particular mention.

Water is almost always a contributing factor in the failure of both natural and man-made slopes. Consequently, whatever the main remedial action may be, attention to drainage is vital, if only to ensure that the existing drainage is not impeded as a result of the development works. For large landslips on natural slopes, drainage improvements may be the only economical option. In minor cases of instability, in both natural and man-made slopes, appropriate drainage may be effective in itself. The installation of drainage measures, particularly in complex landslips, can be difficult, but correct and careful installation is vital to drain performance. Drainage measures are also likely to need maintenance as subsurface installations, particularly, are prone to progressive deterioration due to clogging by fine particles.

Attention to surface and subsurface drainage associated with existing dwellings is of particular importance for the owners of homes on, or near, hillslopes which may pose stability problems. This is emphasised in suggestions for good maintenance practice presented in PPG 14: Annex 1 (1996), the elements of which are reproduced in Table 14. Adherence to these simple measures may guard against the onset of potentially damaging movements and prevent the need for more costly engineered remedial works once instability has been initiated.

The presence of landslipping does not preclude development at a site, provided the problem is recognised, properly evaluated and effectively remedied and maintained.

Table 14 Suggested good maintenance practice for home owners.

DON'TS	*DO'S*
1. Don't block or alter ditches or drains.	1. Check roof drains, gutters and downspouts to make sure they are clear.
2. Don't allow water to collect or pond.	2. Clear drainage ditches and check them frequently during winter.
3. Don't shift your water or soil problems downslope to your neighbours.	3. Make inspections during winter — this is when problems can occur.
4. Don't landscape the slope without notifying the Local Authority.	4. Watch for water-backup inside the house at sump drains and toilets, since this indicates drain or sewage blockage.
5. Don't clear vegetation off slopes without replanting.	5. Watch for wet spots on the property.
	6. Consult an expert if unusual cracks, settling or land slippage occurs. Inform Local Authority of any problems.
	7. Regularly inspect scarp slopes for potential rockfall or loose debris.
	8. Regularly inspect swimming pools and ponds for leaks and repair if necessary.

(From Geomorphological Services Limited, 1991)

10 Engineering ground conditions

Introduction

Ground conditions in the Bradford Metropolitan District vary markedly from place to place depending on the physical and chemical properties of the ground materials, the topography, ground and surface waters, and past and present human activity. For example, the characteristics of areas with bedrock at outcrop differ greatly from those where there is a cover of thick unconsolidated superficial deposits. Man-made deposits such as waste tips and infilled land may give rise to particularly difficult ground conditions and are a matter of some importance because such deposits are abundant in urban and urban-fringe settings where a great deal of building and construction activity is concentrated. In the eastern and southern parts of the District ground conditions are greatly influenced by the presence of underground voids associated with past mineworking for both coal and sandstone.

Good land for building and construction is a valuable resource, and ground conditions across the area are important for the identification of land suitable, or acceptable, for urban regeneration and development. The following section provides a general description of the ground conditions in the District with respect to engineering behaviour which, in conjunction with the relevant thematic maps and other sections of this report, is intended to provide general guidance only. The variability in ground conditions, which may occur even over small sites, means that a study of existing site records followed by a careful and appropriate site investigation should be undertaken prior to any development.

Descriptions of the engineering ground conditions associated with the bedrock and superficial deposits in the District are based on data which were available from the geological mapping, selected site investigations in the area, published data for the same or similar formations in other areas and the geotechnical databases created for other localities which have been the subject of applied geological studies by the British Geological Survey for the Department of the Environment.

Engineering classification of rocks and soils

The general distribution of engineering ground conditions is presented on Map 7 where, for engineering purposes, the geological materials of the District are broadly divided into 'soils' and rocks'. In general terms, engineering soils can be excavated by digging and comprise the superficial deposits shown on Map 3. Engineering rocks comprise the harder more competent bedrock strata shown on Map 2 which, unless highly weathered, usually require a more vigorous means of excavation other than digging. Within this broad two-fold division, the rocks and soils are grouped on the basis of lithology and similar geotechnical characteristics into 'engineering geology units' shown in Table 15. These units form the basis of the description of the engineering ground conditions in the District and their distribution is presented on Map 7.

The distribution of the engineering geological units does not necessarily correspond with the geological divisions presented on the geological maps. For example, the bedrock geology comprising the Millstone Grit and the Coal Measures are distinguished on Map 2 as two separate stratigraphical groups, each consisting predominantly of interbedded mudstones, siltstones and sandstones. On Map 7 a two-fold division has been made into 'moderately strong sandstones' and dominantly fine-grained 'mudrocks' because the Millstone Grit and Coal Measures each consist of these two dominant lithologies with broadly corresponding engineering characteristics. Similar criteria apply for the disparity between the divisions for the engineering soils shown on Map 7 and the superficial deposits shown on Map 3.

Mudrock terminology

'Mudrock' is used here as a collective term to describe a group of fine-grained siliciclastic (non-carbonate) sediments that have a dominant grain-size in the clay or silt grades (<63 μm), are generally similar in engineering characteristics and present broadly similar problems in their investigation, their use and in design (Anon, 1981). Mudrocks include those materials commonly known as siltstones, mudstones, claystones and shales (Table 16), lithological terms which, individually, do not necessarily describe the character of such materials *en masse*. It is a convenient term by which to distinguish the mudstone- and siltstone-domInted sequences from the sandstones of the Millstone Grit and Coal Measures.

In addition to their particle size, an important genetic feature of mudrocks is their tendency to weaken markedly when relieved of overburden pressure due to associated softening and breakdown of interparticle bonds. This degradation process is continued during weathering, ultimately leading to the formation of a normally consolidated soft clay, or silty clay.

In the Bradford District, an unusually hard siliceous siltstone, the Keighley Bluestone, crops out to the west of Keighley. Used in the past for high quality road aggregate, this hard, silica-cemented siltstone is very resistant to breakdown by weathering and does not, on this basis, strictly adhere to the above description of a mudrock. The Keighley Bluestone forms a distinctive unit within the 'mudrock' sequences which, in engineering terms, can be described as a very strong, fine-grained, cemented siltstone. Because of its limited extent, this siltstone has not been distinguished as a distinct 'engineering geological unit' on the 1:100 000 scale map of engineering ground conditions (Map 7). The Keighley Bluestone is, however, shown as a distinct geological unit on the 1:25 000 scale bedrock geology map (Map 2).

Thickness of superficial (engineering soil) deposits

Superficial deposits of variable thickness obscure the solid bedrock over significant parts of the District. In addition to the material characteristics of these materials, the thickness to which they are developed also has an important influence on the engineering ground conditions from place to place. An indication of natural superficial (drift) deposit thickness overlying bedrock is presented on Map 7 by using colour shading and inclusion of the '5 metre' superficial thickness contour line (in red). For example, the colours used to represent the engineering geological units

Table 15 Engineering geological units in the City of Bradford Metropolitan District.

ENGINEERING GEOLOGICAL UNITS		GEOLOGICAL DEPOSITS
SOILS		
MIXED COHESIVE/ NON-COHESIVE SOILS	Stiff/dense	Till
	Soft-firm	Head
	Soft/loose	Alluvium; Glaciolacustrine Deposits
NON-COHESIVE SOILS	Medium dense	Alluvium Fan Deposits; River Terrace Deposits; Glaciofluvial Deposits; Hummocky Glacial Deposits
ORGANIC SOILS	Very soft	Peat
HIGHLY VARIABLE ARTIFICIAL DEPOSITS		Made Ground Infilled Ground
LANDSLIP DEPOSITS (may include displaced bedrock)		Landslips
BEDROCK		
'STRONG' SANDSTONES		Sandstones of the Millstone Grit and Coal Measures
Mudrocks		Mudstones, claystones, shales and siltstones of the Millstone Grit and Coal Measures

Table 16 Mudrock terminology (after Stow, 1981).

Basic Terms				
Unlithified	*Lithified/* non-fissile	*Lithified/Fissile*	*Approx. proportions/grains size*	Collective term
Silt	Siltstone	Silt-shale	>2/3 silt-sized (4–63 μm)	Mudrocks (>50% siliciclastic, >50% less than 63 μm)
Mud	Mudstone	Mud-shale	silt and clay mixture (<63 μm)	
Clay	Claystone	Clay-shale	>2/3 clay-sized (<4 μm)	

relating to the superficial (engineering soil) materials are presented in a lighter shade where they are less than 5 metres thick, the shading being bounded by the '5 metre' contour line. The mapped natural superficial deposit units relate only to the materials at surface. There is insufficient detail to indicate regionally where layers or lenses of other superficial materials occur between those exposed at the surface and the bedrock interface. Other materials than those shown at the surface may be anticipated, for example, below Alluvium and within Till, where sands, gravels and laminated silt-clay lenses are known to be present within the predominantly clay-rich material. Extensive subsurface investigation in such deposits is necessary to determine the variation and distribution of material and geotechnical properties in detail below the ground surface.

Generalised representation of the engineering ground conditions

Three of the most important ground condition considerations with respect to construction and development are the suitability of the ground to support structural foundations, the ease with which it can be excavated and the suitability of the ground materials for use in engineered earthworks and fills. The relevance of these factors for each of the engineering geological units are discussed below and summarised in the key to Map 7. Because of their importance to construction costs and design, they are also presented as separate themes on three small-scale maps to complement Map 7. These maps, at 1:100 000 scale, are: Map 7A — 'Foundation conditions', Map 7B — 'Suitability of deposits as engineered fill' and Map 7C — 'Excavatability'. A fourth map at the same scale, Map 7D — 'Thickness of natural superficial deposits', is also presented to show zones of natural superficial deposit thickness, ranging from 0 to over 20 metres, across the area. The wide variety of engineering ground conditions which exist in the District can be addressed only in general terms in this study, and the degree to which informational details can be presented is limited by the scale of the thematic maps. At scales of 1:50 000, and smaller, the ground condition maps can show only very generalised information. However, by providing a general engineering geological interpretation of the rocks and soils in the District, a principal aim of these maps is to direct users to the larger, 1:25 000 scale, geological maps (Maps 2 and 3) and assist in assessing the engineering implications of the mapped geology. Although the larger scale geological maps allow more accurate location of specific areas of interest, they remain a useful guide only and cannot by themselves, or in conjunction with the other thematic maps, be used as a substitute for appropriate site specific ground investigations.

Engineering rocks (Bedrock)

Undermining

With regard to the engineering characteristics of the bedrock formations (and overlying superficial deposits), consideration must be given to the legacy of mining in the area. Over much of the eastern and southern parts of the District, existing or potential areas of ground subsidence or collapse associated with shallow coal and sandstone workings may be the overriding factor affecting engineering ground conditions. The potential hazard from shallow mineworkings (usually within 30 to 40 m of rockhead), shafts and bell pits are discussed fully in Chapter 8.

Geological faults

Geological faults are planes about which adjacent blocks of rock strata have moved relative to each other. Movement may have been vertical, horizontal or, more likely, a combination of the two. Reactivation of movement along faults may occur in response to the collapse of underground mine workings, occasionally causing earth tremors. They are commonly complex, sheared zones rather than discrete planes and contain weakened and fractured rock which promote deep weathering profiles and varying bearing capacities. Lithologies with differing strengths and settlement characteristics may lie juxtaposed on either side of a fault, and foundations straddling this contact may suffer differential settlements. This may not be a severe problem for light to moderately loaded structures, but heavy structural loads should be taken to founding levels where differential settlements are of an acceptable magnitude. Faults may also provide preferential pathways for water, leachates and even gases. Site investigations should therefore aim to determine the presence and extent of faults prior to planned development and construction.

Weathering

Weathering of the bedrock causes eventual breakdown and softening of the fresh material into an engineering soil, and the depth and degree of weathering is of particular importance with regard to engineering ground conditions in the District. The variability of the weathering products precludes the identification of distinct mappable profiles in this study, but the effects of weathering on the engineering properties of the bedrock units are described below. Weathering grade terminology used in this report (e.g. 'fresh', 'slightly weathered', 'highly weathered', 'residual soil', etc.) follows that given in BS 5930: 1981a for the weathering of rock masses (Figure 22a). A review of the description and classification of weathered rocks for engineering purposes by the Geological Society Engineering Group Working Party (Anon 1995), concluded that a formal classification may not always be appropriate. Guidelines to a range of approaches for classifying weathered rock materials are suggested depending on geological conditions, scale of the problem, exposure available and requirements of the engineering problem in hand. These approaches are summarised in Figure 22b.

'Strong' sandstones *[Sandstones of the Millstone Grit and Coal Measures]*

These sandstones are grey to greyish brown, moderately to well-jointed, generally moderately strong to strong (based on intact strength of fresh or slightly weathered rock), variably micaceous, locally conglomeratic, fine- to very coarse-grained (in the Millstone Grit) and fine- to medium-grained (in the Coal Measures) quartzose sandstones, with occasional siltstone and mudstone interbeds and coal partings. Bedding separation ranges from about 20 to 200 mm (very thinly to thinly bedded, or 'flaggy'), to over 2 m (thickly bedded or massive), and well-developed cross-bedding is common. Individual units range in thickness from thin impersistent bands within the mudrock lithologies to thick regionally persistent units such as the Rough Rock, Addingham Edge Grit and the Woodhouse Grit.

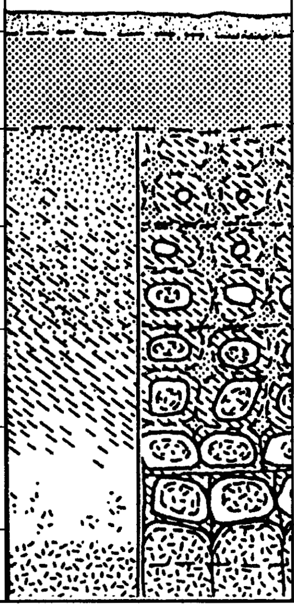
The depth and intensity of weathering is variable, but where exposed the complete weathering of the sandstones to a silty clayey sand or very sandy clay containing weathered sandstone fragments, often occurs to depths of 0.5 to 1.5 m (although residual sandy soils up to 5 m thickness are not uncommon in the Coal Measures). The change from residual soil to weathered rock is generally fairly distinct. The thickness and character of the weathered zone may vary markedly in the vicinity of faults, where locally steep bedding dips and fracturing have enhanced permeabilities. In these areas, 'pockets' of highly weathered sandstone rock have been encountered to depths in excess of 11–12 m below ground surface. The degree of weathering is a major factor in controlling engineering behaviour of the sandstones from site to site, particularly where faulted.

Sandy soils developed over the sandstone outcrops are generally of low to intermediate plasticity, but some records indicate that high plasticity materials are present. This may reflect the presence of mudrock layers or laminae within the weathered sandstone sequences or, more likely, the presence of Head deposits, which are often difficult to distinguish from the *in situ* sandstone weathering profiles on borehole logs. Standard penetration tests (SPT's) in completely weathered sandstone and sandy residual soils generally record N-values indicative of medium dense to dense sands with values, and hence bearing capacities, increasing with depth.

In situ permeability of the sandstones can be expected to vary markedly across the outcrops depending on the degree of weathering, the size and spacing of joints and the presence of fault-zones. Where large or closely-spaced discontinuities occur, moderate or high field permeabilities (c.10^{-5} to over 10^{-2} m/sec) may be expected. Intact sandstone, with no or few joints or fractures, is likely to be only slightly to moderately permeable (less than 10^{-5} to 10^{-2} m/sec).

From BGS geotechnical database records and the supplementary testing of 28 rock samples carried out for this study (Appendix 14.5), uniaxial compressive strengths for intact, fresh to slightly weathered, fully saturated rock generally range from about 25 to 60 MPa, thus classifying the sandstones as 'moderately strong' to 'strong' (BS 5930: 1981a). These test values, recorded for fully saturated samples, represent minimum intact strengths.

Figure 22(a) Scale of rock mass weathering grades (based on BS5930: 1981).



Weathering Grade/ Descriptor	Mass Description
Humus / topsoil	
VI Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.
V Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.
IV Highly weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.
III Moderately weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as corestones.
II Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.
I Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.

Scale of rock mass weathering grades based on BS 5930 (1981). Idealised weathering profiles are shown schematically without corestones (left) and with corestones (right). This scheme is most effectively applied to rocks which are strong to moderately strong in their fresh state and which show a clear gradation in engineering properties during weathering. The terms used to describe weathering states of the bedrock in this report are those based on this scheme.

Measured strength values can vary markedly with degree of saturation of the test specimen and must be accounted for when assessing intact rock strength for design purposes. For example, tests on Elland Flags in the city centre of Bradford have shown that saturated compressive strengths can be up to 60% lower than those recorded on dry specimens. Rock strength decreases with increased weathering, and it should be remembered that tests on intact laboratory specimens do not fully represent the *in situ* strength of the rock mass, which is largely influenced by the frequency, orientation and nature (e.g. infilled or 'clean') of the discontinuities.

Design Considerations

i) Foundations

Provided the nature and depth of the weathered zone is properly assessed, the sandstones generally offer good foundation conditions (Map 7A), but in the eastern and southern parts of the District, existing or potential subsidence due to collapse of underground voids associated with shallow coal and sandstone mineworkings (within 30-40 m of rockhead) may be the overriding factor in bearing capacity/settlement considerations and foundation design. Adequate provision should therefore be made in site investigations to ascertain not only the thickness and founding characteristics of the sandstones, but also the extent and depths of these workings before consideration is given to the appropriate foundation design (see Chapter 8 for a general discussion on potential hazards, site investigation requirements and remedial measures). Fault zones may give rise to adverse groundwater conditions in addition to potentially severe differential settlements. Pretreatment of faulted ground may be necessary, and site investigations should aim to delineate these problem areas as accurately as possible prior to placing foundations.

Where the bedrock profile consists of (usually thin) alternating bands of sandstone and mudrocks, the weathered zone may include bands of stiff clay, derived from decomposed mudrock lithologies, underlying less weathered and more resistant sandstone. Such a situation could have important implications for foundation design if the residual clay layer is not proved by penetration of the sandstone during site investigations.

Because of the potentially wide range of rock conditions, it is sensible to use the results of *in situ* testing (e.g. plate loading tests) to assess the bearing capacity and settlement characteristics at particular sites. For shallow foundation levels in the weathered zone, allowable bearing pressures will be much lower than those for thick layers of fresh or slightly weathered massive sandstone. Both driven piles and bored cast *in situ* piles have been used to carry foundation loads through overlying superficial deposits into sandstone bedrock. Driven piles have disadvantages in that they tend to cause shattering and may 'hold up' on thin sandstone layers underlain by severely weathered shale or mudstone. Bored cast *in situ* piles are generally to be preferred as they can more readily penetrate the weathered zone and the materials passed through can be identified (in some cases, inspection of the base can also be carried out to confirm sound bedrock). Site investigations should be sufficiently detailed to give adequate knowledge of the rocks below the toes of piles. Pile loading tests

Figure 22(b) Approaches to the description and classification of weathered rocks for engineering purposes (after Anon, 1995).

APPROACH 1: FACTUAL DESCRIPTION OF WEATHERING (MANDATORY)

Standard descriptions should always include comments on the degree, extent and nature of any weathering effects at material or mass scales. This may allow subsequent classification and provides information for separating rock into zones of like character. Typical indications of weathering include:

- **Changes in colour**
- **Changes in fracture state**
- **Reduction in strength**
- **Presence, character and extent of weathering products**

These features should be described using standard terminology, quantified as appropriate, together with non-standard 'English' descriptors as necessary to describe the results of weathering. At the mass scale, the distribution and proportions of the variously weathered materials (e.g corestones vs matrix) should be recorded.

Can classification be applied unambiguously? — **NO** → **DO NOT CLASSIFY**

YES

Rock is moderately strong or stronger in fresh state

APPROACH 2: CLASSIFICATION FOR UNIFORM MATERIALS

Grade	Classifier	Typical Characteristics
I	Fresh	• Unchanged from original state
II	Slightly Weathered	• Slight discolouration, slight weakening
III	Moderately Weathered	• Considerably weakened, penetrative discolouration • Large pieces cannot be broken by hand
IV	Highly Weathered	• Large pieces can be broken by hand • Does not readily disaggregate (slake) when dry sample immersed in water
V	Completely Weathered	• Considerably weakened • Slakes • Original texture apparent
VI	Residual Soil	• Soil derived by in situ weathering but retaining none of original texture or fabric

Is a zonal classification appropriate and is there enough information available? — **NO** → Use Rock Mass Classification If appropriate

YES

APPROACH 3: CLASSSIFICATION FOR HETEROGENOUS MASSES

Zone	Proportions of material grades	Typical characteristics
1	100% G I-III (not necessarily all fresh rock)	• Behaves as rock; apply rock mechanics principles to mass assessment and design
2	>90% G I-III <10% G IV-VI	• Weak materials along discontinuities. Shear strength, stiffness and permeability affected
3	50 to 90% G I-III 10 to 50% G IV-VI	• Rock framework is still locked and controls strength and stiffness, matrix controls permeability
4	30 to 50% G I-III 50 to 70% G IV-VI	• Rock framework contributes to strength, matrix or weathering products control stiffness and permeability
5	<30% G I-III >70% G IV-VI	• Weak grades will control behaviour. Corestones may be significant for investigation and construction
6	100% G IV-VI (not necessarily all residual soil)	• May behave as soil although relict fabric may still be significant

Rock is moderately weak or weaker in fresh state

APPROACH 4: CLASSIFICATION INCORPORATING MATERIAL AND MASS FEATURES

Grade	Classifier	Typical Characteristics
A	Unweathered	• Original strength, colour, fracture spacing
B	Partially Weathered	• Slightly reduced strength, slightly closer fracture spacing, weathering penetrating in from fractures, brown oxidation
C	Distinctly Weathered	• Further weakened, much closer fracture spacing, grey reduction
D	Destructured	• Greatly weakened, mottled, ordered lithorelicts in matrix becoming weakened and disordered, bedding disturbed
E	Residual or Reworked	• Matrix with occasional altered random or "apparent" lithorelicts, bedding destroyed. Classed as reworked when foreign inclusions are present as a result of transportation

APPROACH 5: SPECIAL CASES

For rocks whose weathering does not follow other patterns indicated here, such as karst in carbonates and the particular effect of arid climates

From:
Engineering Group of the Geological Society
Working Party report (QJEG, VOL 28, No2, 1995)

should be carried out prior to the main work to confirm chosen loadings and penetrations.

On many sites where Coal Measures rocks occur, the groundwater has been found to have a sufficiently high sulphate concentration to require special measures to avoid attack on concrete (ie. selection of appropriate sulphate-resisting cement in accordance with BRE Digest 363, 1991). Particularly high concentrations have been recorded in the vicinity of colliery tips.

ii) Suitability as engineered fill

Sound sandstone rock may be suitable as rock fill if care is taken in selection and excavation. However, use as a high grade fill may be limited due to the variable amounts of clay and silt-size particles which form the cementing medium of many of the sandstones, and the common occurrence of intercalated clay/mudrock bands. For compaction purposes, the sandstones are generally classed as a graded granular soil.

iii) Excavatability
Excavation methods will depend on the degree of weathering, joint and bedding spacing, and local variations in intact rock strength. Highly to completely weathered sandstone may be excavated by mechanical scraping or digging, whereas fresh or slightly weathered rock may require ripping or pneumatic tools for excavation. Blasting may be needed for major excavations in massive sandstone.

iv) Stability of cut slopes and excavations
Cut faces in massive to moderately-jointed, unweathered sandstone may remain stable at steep angles over the long term, but weathered zones, mudrock interbeds and perched water tables can considerably reduce stability. Excavated slopes in fault zones may require immediate support due to the presence of shattered rock and clay gouge of low shear strength.

Mudrocks *[Mudstones, shales, claystones, siltstones and subordinate seatearths and coals of the Millstone Grit and Coal Measures]*

The mudrocks encompass fine-grained sedimentary rocks whose general geotechnical characteristics are intermediate between those of engineering soils and rocks. The dominant materials are mainly medium to dark grey, moderately fissured, weak to moderately strong mudstones, shales, claystones and siltstones, with subordinate coals and seatearths (unbedded mudstone or siltstone rootlet beds generally underlying coals). The siltstones grade laterally and vertically into mudstones and sandstones with geotechnical characteristics which grade between the two and, with the exception of the Keighley Bluestone (a distinctive, very hard, silicified siltstone), are not distinguished as separate units on the geological map (Map 2).

The mudrocks are particularly susceptible to breakdown due to the effects of weathering and completely weathered, firm to stiff, orange-brown and pale grey mottled clays of low to medium, and sometimes high, plasticity commonly occur within 2 to 5 m of rockhead, followed by a gradual transition through less severely weathered material into unweathered bedrock. This weathered zone may occur at surface or below a cover of superficial deposits. Locally, zones of highly weathered material comprising softened mudrock clasts in a silty clay matrix may occur to depths of about 10 to 15 m, and possibly deeper in fault zones. The degree of weathering is a major factor in controlling engineering behaviour from site to site, particularly in the vicinity of faults.

The mudrocks can be expected to be of generally low to medium compressibility, although high consolidation settlements have been recorded locally and are to be anticipated in weathered zones. Standard penetration tests (SPT's) record a wide variance of N-values depending on weathering grade.

Slight to moderate field permeabilities (ranging from c.10^{-6} to 10^{-4} m/sec) are not uncommon in the mudrock sequences but will vary from place to place depending on weathering grade, fissuring and the presence of interbedded siltstones, sandstones and coal horizons. Waterlogging of the ground may occur locally where the mudrocks are weathered to clay and where mudstone seatearths crop out.

Design Considerations

i) Foundations
Provided the nature and depth of the weathered zone is properly assessed the mudrocks should provide good foundation conditions. However, underground voids associated with shallow coal and sandstone mineworkings (usually within 30–40 m of rockhead) may be the overriding factor in bearing capacity/settlement considerations and foundation design in the eastern and southern parts of the District. Adequate provision should therefore be made in site investigations to ascertain the thickness and founding characteristics of the mudrocks, and also the extent and depths of these workings before design and placement of appropriate foundations (see also Chapter 8).

Shrinkage of clay soils may result from a reduction of soil moisture due to prolonged dry periods and/or the proximity of trees. Current practice to identify potentially shrinkable clays relies on plasticity index; low, medium to high shrinkage potential being indicated by plasticity indices of 10–20%, 20–40% and >40%, respectively (National House Building Council, 1995). On this criterion, based on BGS database records, the mudrocks in the District generally fall into the low to medium swelling potential category, with high swelling potentials being less common, but still present, in highly weathered zones. The assessment of potential shrinkage should therefore be carried out during site investigations for shallow foundations and, where necessary, proper guidelines followed to ensure appropriate foundation design and placement is undertaken to mitigate against shrinkage effects.

When exposed to wet conditions, some mudrock lithologies may swell, lose strength and deteriorate rapidly to clays. Mudstones or claystones with a low silt content appear to be most susceptible to this weakening process which may result in ground heave, a marked reduction of bearing capacity and loss of side friction for piles. Potential for soil heave should be assessed on the basis of plasticity indices as for shrinkable clay soils and, where appropriate, proper guidelines followed for design and placement of shallow foundations (e.g. National House Building Council, 1995). For major excavations, it is advisable to carry out slaking tests on the mudstone lithologies to assess the likely degree and rate of deterioration and, where appropriate, employ measures to prevent water ingress.

For shallow foundation levels within the weathered zone, allowable bearing pressures will be much lower than those for fresh to slightly weathered, competent mudrocks or sound siltstone. For piled foundations, bored cast *in situ* piles are usually preferred to driven piles. In many cases, penetration of three to four pile diameters into sound mudrock has been necessary to develop sufficient bearing capacity. Borings for piles should be cased through water-bearing strata.

Fault-zones comprising shattered rock and clay gouge may present problems of low bearing capacity and excessive differential settlements, and site investigations should aim to delineate these zones as accurately as possible prior to foundation design.

When coal is encountered at foundation levels the coal should be removed to at least a depth of one metre below foundation level and a suitable inert fill placed between the foundation and the coal as a precaution against spontaneous combustion. An alternative approach may be to opencast the site, which is advisable if previous partial extraction has left potentially hazardous ground conditions. Agreement of the owner (generally the Coal Authority) is required before the coal can be entered or disturbed.

Groundwaters encountered in the mudrocks, particularly in the vicinity of colliery spoil heaps, may have a sufficiently high sulphate concentration to require special measures to avoid attack on concrete, such as the selection of appropriate sulphate-resisting cement.

ii) Suitability as engineered fill
Highly weathered mudrocks are generally classified as 'cohesive soil' for earthwork compaction purposes and fresh to slightly weathered material as 'dry cohesive'. Many of the mudrocks may be successfully used as embankment fill, but the material should be placed as soon as possible after excavation and subjected to minimum construction traffic when wet. These materials are particularly sensitive to compaction moisture contents and need careful control during construction. Mudrock fill may not be suitable for use below light structures due to the potential for shrinkage and swelling associated with changing moisture conditions. Pyrite (iron sulphide) present in the mudrock lithologies may slowly oxidise on excavation and exposure to generate sulphate in acid conditions, requiring the selection of suitably resistant cement for buried concrete structures in engineered mudrock fill.

The well-jointed and extremely hard Keighley Bluestone (a silicified siltstone) is used as a source of high grade road aggregate.

iii) Excavatability
Many of the mudrocks can be readily excavated by mechanical scraping or digging, but ripping or pneumatic breakers may be required for very strong indurated mudstones and siltstones, and for most mudrocks at depth or for major excavations.

iv) Stability of cut slopes and excavations
Temporary excavations in fresh to moderately weathered mudrocks should be stable in the short-medium term but slumping may occur in highly weathered zones. Some mudrocks may be susceptible to deterioration and softening when relieved of overburden pressure and in the presence of water. Siltstone and sandstone beds may give rise to water seepages and accelerated deterioration of cut faces, rain and heavy construction traffic may exacerbate this process. In some cases, temporary cut slopes may need protection (e.g. by covering with plastic sheeting or tarpaulins).

Engineering soils (superficial deposits)

This group comprises both natural superficial (drift) deposits and artificial (man-made) deposits. Natural superficial deposits cover about 60% of the District with considerable variations in thickness from a thin (<1.5 m) veneer of Head or Till on the valley side slopes to thick accumulations of highly variable glaciofluvial and alluvial deposits infilling buried channels to depths, in some cases, of over 50 m below the ground surface (see Maps 3 and 7D). Because of the processes by which they were deposited, the majority of the superficial materials comprise a mixture of variable lithologies. This is reflected in the large group of materials considered as 'mixed cohesive/non-cohesive' soils. However, even the 'non-cohesive' soils group which on a regional scale is dominated by sands and gravels, may contain impersistent layers and lenses of clays and silts.

Mixed cohesive-non cohesive soils

This large group may be may be subdivided on the basis of material consistency and relative density into three engineering geological units: stiff/dense soils; soft-firm soils; and soft/loose soils.

Stiff/dense soils [Till]

This unit comprises the main glacially-derived deposit in the District, shown as 'Till' on the geological maps. Till (often referred to as 'boulder clay') forms an extensive, featureless spread across the District, and typically comprises blue-grey or brown, stiff to very stiff, sandy clay with included sub-rounded pebbles, cobbles and boulders of Millstone Grit or Coal Measures sandstone and, occasionally, Carboniferous limestone. In places, the Till contains layers and lenses of laminated clays, silts, and dense sands and gravels. The irregular and impersistent nature of these bodies makes determination of their areal extent difficult without detailed, closely-spaced subsurface investigation.

Due to weathering, the Till may be soft-firm within 1 or 2 m of the ground surface but in some cases a fissured, stiff-firm desiccated surface zone may be developed above a softer layer which gradually becomes stiffer with depth. Depending on the sand/silt content, the Till matrix consists of clays ranging from generally low to medium, and occasionally high, plasticity. Compressibility is generally low but consolidation settlements may be high in softened Till adjacent to water-bearing sand and silt layers or lenses.

Design Considerations

i) Foundations
Till should present no major foundation problems provided thickness and lithological variations (particularly the presence of water-bearing sand and gravel layers and lenses of laminated silts and clays) are determined during site investigations and accounted for in design. For example, water-bearing sands and gravels below foundation levels in clay Till may cause softening and/or heave, due to artesian conditions, if undetected. The Till cover on moderately steep slopes has frequently been disturbed by landsliding, and where construction is planned in these areas, care should be taken to ascertain current stability conditions and the likely effect on these conditions of excavation and construction. Recorded plasticity indices for clayey Till generally range from about 10–30%, indicative of soils with low to moderate potential for shrinkage. Highly shrinkable soils are unlikely to be encountered in Till within the District.

ii) Suitability as engineered fill
The clay Till (boulder clay) may be suitable as 'cohesive soil' fill if care is taken in selection and extraction. Because of lithological variations selection of suitable material will need to be made on a site-specific basis. Laminated silts and clays which occur locally within the Till are usually unsuitable for use as fill. Clay Till occurring near water-bearing beds of sand and gravel may be similarly unsuitable.

iii) Excavatability
Till may be machine-dug with the prospect of hard digging in very stiff over-consolidated material with included cobbles and boulders. Ponding of surface water in low permeability boulder clay may cause problems during working.

ii) Stability of cut slopes and excavations
Temporary cuts or excavations in 'homogeneous' boulder

clay should remain stable in the short-medium term, and possibly long term in low cuts. The presence of layers or lenses of laminated silts/clays will reduce stability considerably, as will sand and gravel horizons resulting in perched water tables and increased seepage. Where these materials are exposed in excavations, immediate side support may be required.

Soft-firm soils *[Head]*

Head deposits are poorly sorted, poorly consolidated deposits derived from bedrock and other natural superficial deposits by slow downslope movements of saturated materials due to present day hillcreep and past periglacial freeze-thaw processes. Such deposits are variable in composition but most commonly comprise a soft to firm sandy, silty clay or clayey silt of low to intermediate plasticity, with included scattered stones and cobbles; locally it may be a gravelly silty sand or clayey sandy gravel. The variable composition reflects the local derivation. Head commonly forms an extensive cover on the lower slopes of all the exposed bedrock, usually as a thin veneer less than a metre thick, but greater thicknesses may have accumulated at the foot of slopes and in hollows. Thicknesses ranging from less than 1 m to about 6 m are recorded in many site investigation reports, but the distinction between *in situ* weathered bedrock material and Head is generally unclear, the one grading into the other. However, in contrast to the weathered *in situ* soils, Head deposits tend to show more variable and generally higher compressibilities, more variable rates of consolidation settlement, and generally lower shear strengths.

Low shear strengths are often related to the presence of relict shear surfaces which may develop in the Head as a result of sliding movements associated with its derivation from freeze-thaw processes. Such deposits are often marginally stable and prone to landslipping, even on shallow slopes, if stability conditions are adversely affected by excavations or loading. Site investigations should therefore aim to establish the extent, thickness and nature of the Head deposits so that stability conditions can be ascertained prior to site work.

The mapped distribution of Head generally greater than about 1 m thick is shown on Map 3, but this is not fully representative. It should be assumed to occur elsewhere as a patchy veneer of varying thickness which should be ascertained prior to the design of foundations or cut slopes.

Design considerations

i) Foundations
Head deposits offer generally poor foundation conditions due to their variable thickness and composition, the possible presence of soft compressible zones and their generally low shear strength often related to the presence of relict shear surfaces. Where feasible, Head deposits should be removed prior to placing foundations. Their generally shallow thickness (usually less than 1.5 m) often enables economic removal, but on sloping sites, care must be taken to ensure that the marginal stability of these deposits is accounted for prior to excavation.

ii) Suitability as engineered fill
Head deposits may be suitable as bulk fill but, locally, may be too wet to achieve satisfactory compaction.

iii) Excavatability
Head deposits are easily excavated by mechanical digging. Clayey Head is effectively impermeable and may cause problems during working due to ponding of water in depressions.

iv) Stability of cut slopes and excavations.
Until proven otherwise, Head deposits should be considered as marginally stable. Where relict shear surfaces are present, shear strengths on these surfaces will be at or near residual values and this should be accounted for in slope design calculations.

Soft/loose soils *[Alluvium; Glaciolacustrine Deposits]*

Alluvium deposits occur extensively along the valleys of the rivers Aire and Wharfe, and as thin discontinuous strips in tributary valleys. They are extremely variable in composition, consisting of very soft to firm sandy, silty clays and silts of low to intermediate plasticity, with impersistent peats and organic clays; and loose to dense, fine to coarse-grained sands and gravels with clay lenses. The cohesive and non-cohesive materials may occur as layers or impersistent lenses one within the other. In the near surface zone the clayey alluvium may become desiccated and assume a stiffer consistency and higher strength than softer underlying material. At many locations, particularly in the Aire Valley, the soft surface units of the Alluvium have been removed and replaced with fill. Glaciolacustrine deposits occur at surface only in a small area at Bingley [SE 10 40], although they have been proved from boreholes to occur extensively in buried channels beneath the Alluvium of the rivers Aire and Wharfe. These deposits are of glacial lake origin and mainly comprise soft to firm silty clays and silts with thin sand laminae, or laminated sequences of clays and silts of low to sometimes high plasticity. These deposits are laterally impersistent, interdigitating with Till and granular Glaciofluvial deposits.

Depths and thicknesses of the Alluvium and Glaciolacustrine deposits vary considerably across the area but in the main channels of the Wharfe and Aire Alluvium may exceed 15–20 m thickness. Combined thicknesses of Alluvium and Glaciolacustrine deposits may exceed 40 to 50 m, for example in the Keighley area where 42 m of these deposits have been recorded. The silt/clay units within both deposits may be expected to exhibit medium to very high compressibilities with very slow rates of consolidation settlement, particularly where soft organic clays and peats are present. The Glaciolacustrine clays are generally more plastic than the alluvial clays and possess highly anisotropic shear strengths due to their laminated structure (horizontal shear strengths are usually low).

Design Considerations

i) Foundations
Low bearing capacities, high compressibilities, high groundwater tables and water uplift pressures, and the likelihood of excessive total and differential settlements pose problems for foundations in the Alluvium and Glaciolacustrine deposits. Site investigations, often requiring closely-spaced boreholes, should aim to ascertain the presence, depth and extent of soft compressible zones and the depth to sound strata. Due to artificial straightening and natural changes in position of the river channels, abandoned meanders may occur at several locations in the alluvial floodplains of the rivers Aire and Wharfe. It is important that these features (which may contain soft, compressible organic clays and silts hidden beneath man-made deposits) are identified during site investigations prior to development and construction.

Where limited thicknesses occur, wholesale removal and replacement of the Alluvium with suitable fill may be an economic option, but elsewhere alternative solutions are required. Of these, piling and raft foundations are the most commonly used. For heavy structures, bored or driven piles should be used to transfer loads to dense basal gravels or into the underlying bedrock. Mini-piles bearing in dense/medium dense gravels may be suitable for light to moderately-loaded structures. For piles in thicker deposits, consolidation of the alluvial clays may cause 'drag-down' of the loaded pile and this should be anticipated. Raft foundations have been successfully employed for light structures, with large settlements accounted for in design. Very low rates of consolidation settlement may be partly overcome by the use of lightweight fill or staged surcharging, for both structures and embankments.

Groundwaters encountered in the Alluvium may have a sufficiently high sulphate concentration to require measures to be taken to avoid attack on buried concrete.

ii) Suitability as engineered fill
Alluvial silts and clays, often with intercalated Peat, and Glaciolacustrine deposits are generally unsuitable for use as fill. Alluvial sands and gravels may be suitable as 'granular soil' fill if care is taken in selection and excavation.

iii) Excavatability
Alluvial deposits are readily excavated using soft ground excavating machinery but water inflow problems may be encountered.

iv) Stability of cut slopes and excavations
High groundwater levels mean that excavations in the Alluvium are subject to severe water inflow problems and immediate support is normally required to maintain the stability of trench sides and cut faces. Running sands may also be encountered below the water table.

***Non-cohesive soils** [Alluvial Fan Deposits; River Terrace Deposits; Glaciofluvial Deposits; Hummocky Glacial Deposits]*

This group of materials, on a regional scale, consists predominantly of medium dense, fine- to coarse-grained sands and medium dense to dense, fine to medium gravels with occasional cobbles and boulders, with impersistent layers and lenses of clays and silts developed locally. They are associated with Alluvial Fan, River Terrace, Glaciofluvial and Hummocky Glacial deposits which flank the lowermost slopes of the Aire and Wharfe valleys and their tributaries (see Map 3). The present-day river channels have incised through these deposits leaving them as topographic features such as ridges, terraces and mounds aligned irregularly along the outer edges of the river Alluvium (see Chapter 6). Glaciofluvial and Hummocky Glacial deposits also occur as isolated patches in upland plateaux areas. In addition, Glaciofluvial deposits occur as irregular subsurface deposits forming layers, or lenses within or below the Till, or as extensive infill deposits in deep buried channels below the Alluvium and River Terrace deposits in the Aire and Wharfe valleys, where they form thick deposits of bedded sands and gravels with occasional thin and laterally impersistent beds of silt and clay.

Some glacial deposits form prominent hummocky features which distinguish them from the featureless sheets of Till with which they are commonly associated. In contrast to the Till, it is unlikely that these Hummocky Glacial Deposits, comprising an unsorted mass of boulders and cobbles in a variable sandy or clayey matrix, were ever subjected to substantial ice loading, and their engineering behaviour may be more akin to gravelly, clayey Head rather than an overconsolidated boulder clay.

Design considerations

i) Foundation conditions
The non-cohesive soil deposits encountered at surface outcrop should offer good foundation conditions provided thicknesses and lithological variability is confirmed during site investigation. Compressibilities are likely to be low to moderate in these deposits which are generally well-drained, with water tables below the normal depth for shallow foundations. Perched water conditions are unlikely due to the impersistent development of clay sequences. In the Aire and Wharfe valleys, care should be taken to identify and ascertain the depth and material characteristics of Glaciofluvial deposits occupying deep infilled channels below the Alluvium and River Terrace deposits, particularly during site investigations for heavier structures. In this situation, laminated Glaciolacustrine silts and clays tend to interdigitate with the sands and gravels, giving rise to impersistent soft compressible zones, the extent and depth of which may be difficult to determine without detailed sub-surface investigation.

Checks should be made at specific sites during ground investigations to ascertain the sulphate content of groundwaters and, where appropriate, measures taken to protect attack on buried concrete.

ii) Suitability as engineered fill
Alluvial fan, Glaciofluvial and River Terrace deposits should be suitable for use as 'granular soil' (sand/gravel) fill, if care is taken in selection and excavation. Hummocky Glacial deposits, usually more variable in composition, may be suitable as a source of granular fill but may contain high proportions of mudstone and/or clay.

iii) Excavatability
Surface deposits are easily excavated by mechanical digging. Running conditions may be encountered in sands below the water table, for example in Glaciofluvial deposits in buried channels.

iv) Stability of cut slopes and excavations
Excavations and cut slopes will normally require immediate support. Casing will be required to prevent collapse of granular material into bores. Water ingress should not present problems unless borings or excavations into channel infill are taken below river level when hydraulic continuity may be anticipated.

***Organic soils** [Peat]*

Organic soils mainly comprise deposits of fibrous or amorphous Peat which occur as irregular surface patches on moorland plateaux in the upland northern parts of the District (e.g. Rombalds Moor) and on the western and south western peripheries of the District (e.g. Keighley and Oxenhope moors), and as impersistent layers and lenses of peat or organic (peaty) clays and silts within the Alluvium. Organic soils and peats result in soft ground conditions, and typically possess low densities, high moisture contents and low strengths. All peats suffer very high consolidation settlement on loading. 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, in addition to total settlement, may be a major problem. Settlements may also take place without external loading following drainage induced by lowering of the water table.

Design considerations

i) Foundation conditions
Organic soils and peats offer very poor foundation conditions due to low bearing capacities and high, often uneven, settlements. The limited extent and relatively isolated moorland locations of the mapped surface peats means that they will not generally be encountered in most construction works. However, where this is the case, it is advisable that the surface peats are removed prior to development. Where encountered below normal foundation levels, the presence of soft peats/organic clays should be accommodated for in foundation design. The groundwaters in organic soils and peats may be highly acidic and appropriate precautions such as selection of suitably resistant concrete will normally be required to prevent damage and disintegration of buried foundations, culverts, and pipes (BRE Digest, 1991).

ii) Use as engineered fill
Organic soils and peats are unsuitable under any circumstances for forming load-bearing fills (BS 6031: 1981) due to their low strength, poor drainage characteristics and complex water-holding properties.

iii) Excavatability.
Excavation of upland peat is easily accomplished by hand digging, but machine digging of alluvial peats and peaty clays is usually required when encountered at or below foundation levels. Trafficability will vary according to the nature of the material and local groundwater conditions.

iv) Stability of cut slopes and excavations
Very wet, amorphous, peaty soils will suffer poor face stability and in, extreme cases, flow into the excavation, thus immediate trench support and de-watering may be required. The more fibrous peats may stand well without support.

Highly variable artificial deposits *[Made Ground; Infilled Ground]*

These deposits comprise those materials placed by man on the natural ground surface (Made Ground) or as infill within excavations or worked ground (Infilled Ground). Descriptions of various types of artificial deposits and their composition are discussed in Chapter 6. The distribution of existing artificial deposits, generally over 1.5 m thick, is shown on Map 3 and in summary form on Map 7. These areas, some of which have been subject to extensive landscaping, mainly include:

- Infilled beck valleys
- Made up ground levels on low lying, marshy or soft ground which was often prone to flooding
- Backfilled sludge lagoons
- Backfilled quarries, clay-pits and opencast sites
- Areas of demolished (predominantly terraced) housing stock
- Demolished large industrial sites

The artificial deposits across the District are highly variable in composition, geotechnical properties and thickness (1–2 m thicknesses are common but 10 to over 20 m may occur in areas such as old quarries and opencast sites). The materials consist of chemical, mining and quarry waste, domestic refuse, and construction materials such as bricks, concrete and other rubble, in addition to bulk fill derived from the bedrock formations.

Artificial deposits generated by the disposal of domestic and industrial waste in licensed and unlicensed tips are potentially the most problematical to construction and land use. The material may include a very wide range of inorganic, organic, inert, reactive, combustible, 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 there may be no record of what has been deposited. It is difficult to predict the engineering ground conditions of these sites since they will be highly variable across their area and with depth. Geotechnical properties will also vary with time as material decays, and the nature of old domestic and/or industrial waste sites cannot necessarily be used as a guide to the future behaviour of recent sites because of the changing nature of the waste materials through recent history. Modern waste disposal practices should result in much better ground conditions than in the past and, following thorough site investigation, the use of suitable foundations and sealing and/or ventilation of basements will enable sites to be satisfactory for many end uses.

Not all artificial deposits will present problems. Modern, properly engineered fills, such as highway embankments and controlled opencast infill, may have excellent engineering properties (BS 6031: 1981b). However, some artificial deposits generated by engineering works in the distant past, and when environmental issues were not so highly regarded, may have resulted in present ground conditions which do not reach current standards of engineering and environmental practice. **Unless the dimensions and material nature are known to a high degree of certainty, all sites of artificial deposits should be considered as suspect** because of the likelihood of extreme variability in the composition and compaction of the fill materials (some of which may be hazardous to health or harmful to the environment or building). The investigation of such ground is a specialist task and must be carried out in compliance with current best practice and with regard to the safety of site personnel and the public (BS 5930: 1981a; BRE Digest 274, 1983a; BRE Digest 275; DOE/Welsh Office Joint Circular 21/87:22/87; Anon, 1993b). The Institution of Civil Engineers, Site Investigation Steering Group Report on "Site investigation in construction" (Anon, 1993b) is an essential guide to current practice, of which Part 4 — "Guidelines for the safe investigation by drilling of landfills and contaminated land", is particularly relevant.

Detailed assessment of the ground conditions pertaining to the areas of artificial deposits shown on Maps 3 and 7 was not feasible, but the following points should be borne in mind:

- where fill has been placed above ground level, as in infilled becks and made up levels of low marshy ground, it may rest on soft alluvial clays or peats which may themselves undergo excessive differential consolidation settlement when loaded; this will be additional to that resulting from the compression of the fill itself. Therefore the stability of the ground underlying the fill may need to be examined.

- if structures are built on piles passing through the fill into underlying strata, negative skin friction caused by the fill settling under its own weight may be a major consideration in foundation design.

- where the fill is deep, self-weight will often be the principle cause of long-term settlement. With granular fills and poorly compacted unsaturated fills of all types, the major compression occurs almost immediately and consequently most of the settlement due to self-weight occurs as the fill is placed. Nevertheless, significant further movements ('creep' settlement) do occur under conditions of *constant* effective stress and moisture content. With many fills the rate of creep compression decreases fairly rapidly with time and shows an approximately linear relationship when plotted against the logarithm of time elapsed since the deposit was formed (Figure 23). It should be remembered that an increase in stress due to changes in applied load or moisture content may cause much greater movements than those shown in Figure 23.

- compression of fills by building loads will be very variable depending on the nature of the fill, its particle size distribution, compactness, the existing stress level, the stress increment and the moisture content. Assuming the stress increments due to building loads do not bring the fill close to bearing capacity failure, settlements can be most simply calculated using a compressibility parameter related to one-dimensional compression. This parameter, the constrained modulus, is defined as $\Delta\sigma_v/\Delta\epsilon_v$, where $\Delta\sigma_v$ is an increment of vertical stress, and $\Delta\epsilon_v$ is the increase in vertical strain produced by $\Delta\sigma_v$ Some typical values of constrained modulus for different fill types are shown in Table 17. It should be realised that movements which occur during building construction are likely to be much less of a problem than those which occur *after* completion of the structure. The long-term creep component is therefore of particular significance (see above).

- loose unsaturated fill materials are usually liable to collapse settlement following inundation with water. If this occurs after construction, a serious settlement problem may arise. It is believed that this is often a major cause of settlement problems in building development on restored opencast mining sites. Problems can also be caused by water penetrating into the fill from the surface through deep trench excavations for drains associated with building development.

- when fine material is placed underwater, as in sludge lagoons, a soft cohesive fill is formed which is characterised by low permeability. Settlement is controlled by a consolidation process in which excess porewater pressures dissipate slowly as water is squeezed out of the voids in the fill. This type of fill may be susceptible to liquefaction, and often a firm but thin crust, overlying very soft material, may form over the surface of the lagoon deposit.

- excessive differential settlements, leading to distortion and damage to buildings, are to be expected in highly variable poorer types of fill, or where the depth of fill changes rapidly. Where the deposits backfill a pit or quarry, they will invariably be less compacted than the surrounding natural ground, leading to differential settlement in foundations that straddle the edge of the filled area.

- at sites in areas of demolished industrial buildings and housing, load-bearing walls may be present at, or close to, the surface of the fill. New foundations built across such walls and the surrounding fill are liable to severe differential settlements. Such sites may also contain basements, cellars, tunnels and service ducts which may be only partially filled with rubble and often remain as complete voids.

- the problem of differential settlement may be compounded in cases where cavitation results from chemical or bacterial breakdown of the fill material.

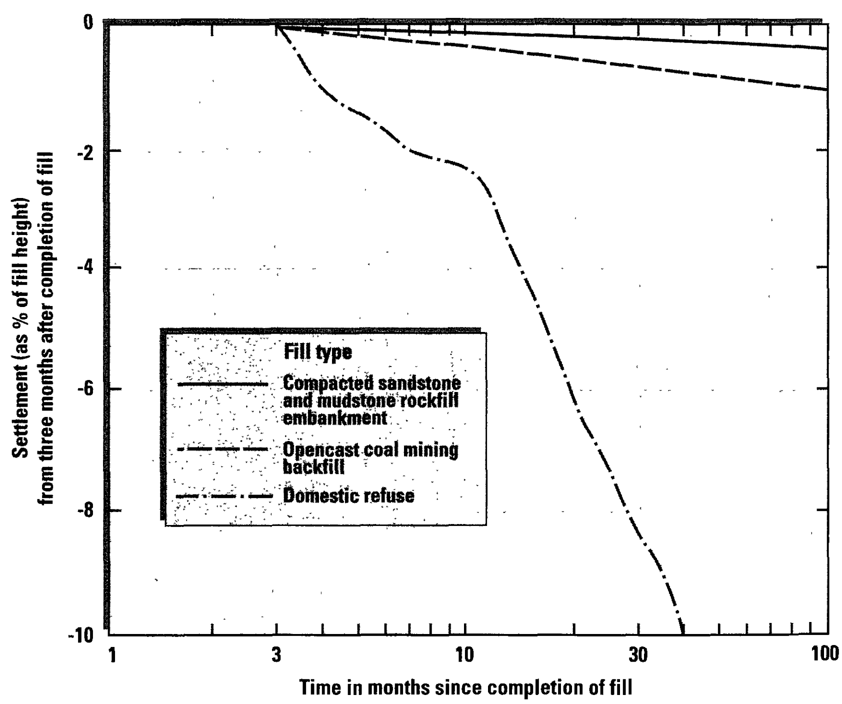


Figure 23 Settlement rates of different types of fill (vertical compression plotted against $\log_{10}$time) [from BRE Digest 274].

Table 17 Compressibility of fills (from BRE Digest 274).

Fill type	Compressibility	Typical value of constrained modulus (kN/m^2)
Dense well-graded sand and gravel	very low	40 000
Dense well-graded sandstone rockfill	low	15 000
Loose well-graded sand and gravel	medium	4 000
Old urban fill	medium	4 000
Uncompacted stiff clay fill above the water table	medium	4 000
Loose well-graded sandstone rockfill	high	2 000
Poorly compacted colliery spoil	high	2 000
Old domestic refuse	high	1 000–2 000
Recent domestic refuse	very high	—

- fill comprising industrial waste may be potentially chemically active and capable of generating dangerous or combustible gases and toxic leachates.

- domestic refuse will generate methane gas, which is highly combustible. The accumulation of methane in closed spaces in buildings, sub-floor spaces or basements may reach explosive concentrations (5–15% in air).

- colliery spoil, which constitutes a significant part of the Made Ground in the south-east of the District, may be liable to spontaneous combustion, as has been recorded from a site at Odsal [SE 16 30]. In addition, pyrite (iron sulphide) present in colliery spoil is prone to oxidise and produce sulphate-rich, acidic groundwater leachates causing corrosion problems for buried foundations. The leachates may also affect the quality of surface water.

Landslip deposits

The distribution of landslip deposits in the area are shown on Maps 2, 3, and 7. On Map 6, landslip deposits are shown in relation to zones of slope steepness. Landslips are a common feature in the District and their nature, formational processes and relevance to planning and development are discussed in Chapter 9. Salient points with regard to engineering ground conditions are summarised, briefly, below.

- Landslip deposits vary widely in composition from dominantly clay to variable amounts of clay, mudrock and sandstone debris, derived mostly from Till and weathered bedrock. They are bounded by, and/or contain within them, slip (or shear) surfaces of low strength. Rockfall detritus, sometimes of considerable extent, may be developed at the foot of major sandstone backscarps, covering, and incorporated within, landslip deposits mantling the slopes below (prime examples being the large landslips developed in the Wharfe valley above Ilkley; see Plates 2 and 17).

- The presence of landslip deposits indicate areas of current or past instability. Therefore it is essential that these areas are identified and the stability conditions, not only of the immediate site but also the adjacent slopes, are established by focused site investigation prior to planned development and construction. Where necessary, properly engineered remedial measures to enhance stability should be undertaken by competent professionals, ensuring that the effect of any site development (e.g. construction loads, excavations and/or modification to the groundwater regime) on stability is accounted for in design.

- Wherever possible, development on landslip deposits should be avoided. If this is not feasible, it is essential that the ground is made suitable by appropriate engineered remedial works. The investigation of such ground is a specialist task and must be carried out in compliance with best current practice. Useful guidance for development on unstable land is given in the Planning Policy Guidance Note 14 — "Development on unstable land" (Department of the Environment, 1990). Annex 1 (1996): "Landslides and planning" is of particular relevance.

- Landslip deposits are generally unsuitable for use as engineered fill due to their often highly variable composition (e.g. clay, boulders, vegetation), the presence of wet zones associated with seeps and springs, and the risk of initiating further instability during excavation. Isolated upland hillslope locations, difficult access, and/or the limited extent of many landslip deposits make their use as a source of fill material unviable.

Summary and recommendations

Engineering ground conditions vary markedly across the District in response to the material and geotechnical characteristics of the geological materials, topography, ground and surface waters and past and present human activity. Over most of the area, the ground conditions should pose no major problem to engineering development, provided that adequate information to properly confirm ground characteristics is obtained for specific sites. This should involve reference to existing information (e.g. borehole records and site investigation reports) during desk studies, followed by competent and properly focused site investigations at the feasibility and design stages of planned development projects.

A variety of general problems may be encountered during development and construction in the District, although virtually all could be overcome by modern engineering methods, at varying cost. The most significant, particularly with respect to foundation conditions, are the following:

- Shallow undermining
- Landslips
- Faults
- Variability of natural superficial deposits
- Variability of made and infilled ground (man-made deposits)

Shallow undermining

In the east and south of the District, existing or potential subsidence due to collapse of underground voids, shafts and bellpits associated with shallow coal and sandstone workings within 30–40 m of rockhead may be the overriding factor in bearing capacity/settlement considerations and foundation design (see Maps 5, 7 and 7A). This pertains to structural loads placed on, or taken down to, bedrock and for built development on covering superficial deposits. Site investigations in these areas should therefore aim to ascertain not only the thickness and geotechnical characteristics of the geological materials, but also the presence, extent and depth of these workings before consideration is given to appropriate foundation design. In many cases ground treatment to ensure stability may be required. Recommendations for site investigation techniques and remedial measures in undermined areas are given in Chapter 8.

The zones of shallow undermining shown on Maps 5, 7 and 7A represent areas where *colliery-based* workings occur, or are likely to occur, within 30 m of the *ground surface*. Because the cover of superficial deposits in these areas is usually less than 5 m, the delineated zones approximate closely to areas of undermining within 30 m of *rockhead*. Shallow sandstone workings are known to occur to depths of c.40 m below ground surface with the height of the workings approximating to the thickness of the worked sandstone bed (which may be up to 6 m). The location and extent of old sandstone workings is difficult to predict and they may occur within and beyond the zones of shallow colliery-based undermining shown on the maps. Where known, the locations of shallow sandstone workings are shown on Map 5 only.

Landslips

Landslips are of common occurrence on moderate and steep slopes in the District (see Map 6). The presence of landslip deposits indicates areas of current or past instability. Therefore it is essential that these areas are identified and the stability conditions of the immediate site **and** the adjacent slopes are established by site investigation prior to planned development and construction. Wherever possible development on landslip deposits should be avoided, if this is not feasible it is essential that the ground is made suitable by appropriate engineered remedial works. This is a specialist task and, where necessary, engineered remedial measures to enhance stability should be undertaken by competent professionals, ensuring that the effect of any site development on stability is accounted for in design. Recommendations for site investigation techniques and appropriate remedial measures in areas of landslipped ground are given in Chapter 9.

Faults

Geological faults are numerous in the District and give rise to zones of sheared, weakened and fractured rock which promote deep weathering profiles and varying bearing capacities. Weathering of the bedrock units in the District is an important factor affecting engineering ground conditions and the degree and depth of weathering associated with fault zones are particularly pronounced. Lithologies with differing strengths and settlement characteristics may lie juxtaposed on either side of a fault and foundations straddling this contact may suffer severe differential settlements which should be accounted for in design. Faults may also provide preferential pathways for water, leachates and even gases. Site investigations should therefore aim to determine the presence and extent of faults prior to planned development and construction. In addition to boreholes and trial pits, the contrast between *in situ* bedrock and shattered, weakened and wetter rock in fault zones makes the use of geophysical methods (e.g. electrical resistivity and electromagnetic techniques) particularly suitable for detection and delineation of these features (Anon, 1988). These techniques can also greatly assist in the optimum siting of boreholes and pits, especially where fault zones are obscured by a thin cover of superficial deposits or where shallow surface weathering of the bedrock grades laterally into the deeper weathered profiles associated with faults.

Variability of natural superficial deposits

The natural superficial, or drift, deposits cover approximately 60% of the District and their variability in both thickness and material characteristics is a major factor controlling the engineering ground conditions from place to place. The thicknesses of natural superficial deposits are generally less than 5 m across most of the District but where they infill deep glacial channels, broadly following the modern Aire and Wharfe valleys, thicknesses exceeding 50 m are attained (see Maps 3 and 7D). Determination of the thickness of these deposits is particularly important with respect to tunnel construction and the design of foundations for medium or heavy structures which need to be founded on a solid sub-stratum. Tunnels in poorly consolidated deposits will normally need to be lined immediately after excavation and additional problems may be encountered where thick permeable natural superficial deposits give rise to severe water inflows, or where the tunnel drive passes from unconsolidated natural superficial deposits into bedrock. For medium and heavy structures, natural superficial deposit thickness will determine, for example, whether excavation or piling to rockhead is the most cost-effective foundation option. Because of the processes by which they were deposited, the majority of the natural superficial materials comprise a mixture of clays, silts, sands, gravels and sometimes organic soils in various proportions and dispositions. Potential settlement problems are most likely to be encountered where impersistent or irregular subsurface layers or lenses of contrasting materials occur within another dominant lithology (e.g. water-bearing sand and gravel layers within dominantly clayey Till, or weak, laminated silts and clays of glaciolacustrine origin within Glaciofluvial sands and gravels). The floors of the Aire and Wharfe valleys are the principle areas where complex interdigitation, layering and lensing of variable lithologies are most pronounced, and where potential problems are compounded by deep infilled channels and soft, highly compressible zones associated with peats and organic clays formed in the present day alluvial floodplains.

Site investigations in the natural superficial deposits should aim to establish their thickness (depth to bedrock) and lithological and geotechnical variability as accurately as possible to enable appropriate foundation design. Rapid lateral and vertical changes may make this task difficult without closely-spaced boreholes or trial pits, even on small sites. On larger sites, a multi-disciplinary approach for investigation of the ground is highly recommended. Geophysical methods, for example, in conjunction with boreholes and trial pits can be of particular help in elucidating both the nature of the deposits and the bedrock depth, particularly in deep buried channels. Resistivity and cross-hole seismic tomography surveys are, in combination, a particularly powerful tool for assessing the dimensions of buried channels and nature of the infill. In addition to boreholes, static cone penetration testing (CPT) is also recommended. CPT's (sometimes known as 'Dutch cone' soundings) can provide a rapid means of obtaining continuous profiles of soil stratification by measuring cone resistance and side friction for standard rates of penetration. The ratio of the two, the friction ratio, enables identification of the soil type. Once calibrated with information from a few boreholes, very accurate lithological profiles can be obtained which can be further enhanced by use of an electric piezocone to measure excess pore pressures generated during penetration. Qualitative use of the CPT is particularly valuable in correlating between boreholes in highly variable deposits ranging from soft-firm clays or loose to medium dense sands and gravels. Limitations are its effective operating depth of about 30 m, and the inability of the cone to penetrate very dense gravels or to 'hold up' on boulders. Quantitative use of the CPT is more variable, but good correlations can be achieved between cone resistance and the shear strength of clays and the shear strength and density of sands and gravels.

Variability of artificial (man-made) deposits

Areas of Made Ground and Infilled Ground are highly variable in composition, geotechnical properties and thickness. Properly engineered fills, such as those typically used in the construction of highway embankments, may have excellent engineering properties whereas recently-placed domestic refuse would be at the opposite end of the scale. Because of the likelihood of extreme variability in the composition and compaction of the fill materials (some of which may be hazardous to health or harmful to the environment or building), all sites of artificial ground should be considered as suspect unless the dimensions and material nature are well known.

Ground investigations should involve trial pits and boreholes. Trial pits are particularly useful as they allow large sections of the fill to be inspected. Standpipe piezometers sealed into boreholes should be employed to obtain information about water levels within the fill. With variable fill, small-scale laboratory tests may be of limited use whereas a programme of field tests can provide much important information. The most useful tests on deep fills may be simply to monitor settlement rates of the fill by precise levelling. Stable benchmarks need to be established away from the filled ground, so it is important that the boundaries of the filled area are established by borings and pitting (geophysical resistivity techniques have also proved effective). Simple field loading tests can be useful in some situations since they provide direct evidence of performance. Lightweight structures with strip footings generally stress the ground significantly only to depths of 1.5 to 2.5 m. Consequently, it is relatively simple to test-load the fill to reproduce the actual stress level and distribution with depth. Such tests, however, reflect only the near-surface properties of the fill. In some fills (for example, soil fills without any large hard fragments) cone penetration tests (CPT's) can give an indication of the condition of the fill at depth.

Where buildings are to be founded on fill where site investigation has indicated that significant differential movement may occur over the area of the construction, ground improvement techniques to enhance the load-carrying characteristics prior to development may be a viable solution. Many treatment techniques are essentially methods of increasing the density of the fill (although other methods such as grouting may be applicable in some situations). Treatment techniques may include excavation and refilling in thin layers with controlled compaction, preloading with a surcharge, dynamic consolidation and, for granular soil fill, vibro-compaction. Where the fill is deep, costs of all methods will be closely related to the depth to which the fill is to be treated. Any ground improvement technique considered for use on a filled site should be examined for its cost effectiveness, and in the light of other problems existing at the site, as there may be situations in which a particular improvement method may be beneficial in more than one respect. For example, compaction of colliery spoil will not only improve its load carrying characteristics but may also reduce or eliminate the risk of combustion. In other situations, the opposite may occur. For example, where gases are being generated during organic decay, ground treatment solutions involving vibrotechniques could lead to the formation of paths through which methane gas could enter the foundations of a building.

For relatively large structures built on shallow fill, poor load carrying characteristics can be circumvented by using piled foundations and a suspended floor. The piles should be designed for negative skin friction caused by settlement of the fill. Particular care is needed in fills in which methane gas is being generated as piles could form pathways for the escape of the gas into foundations. In such cases, venting should be carried out prior to development. Where small structures have to be built on deep fill, piling to a firm sub-stratum is not likely to be an economic solution. Reinforced concrete rafts with edge beams have been used but where large differential movements are possible, very substantial foundations may be required. In the foundation design, it is also important to distinguish between settlement due to the weight of the building and that due to other causes such as self-weight of the fill. With small structures on deep fills, the latter will almost invariably predominate and so 'bearing capacity' can be a misleading concept. Foundation design should therefore be based on an assessment of the magnitude of movements of the fill subsequent to construction on it. Problems associated with low-rise buildings on filled ground can be reduced by avoiding building across the edges of filled areas, where the structure would be founded partly on fill and partly on undisturbed ground. Construction should be restricted to small units and long terraces of housing should not be built on existing filled ground. The relative movements between the building and the services entering it also merit careful consideration, for example the use of short pipe lengths with flexible connections.

The investigation of the geotechnical aspects of artificial ground should be integrated with the investigation of other relevant factors which could, in some situations, include chemical attack (on buried pipes and concrete), gas generation, combustibility and toxicity. On some sites special precautions with regard to the safety of site personnel and the public will be necessary. The investigation of such ground is a specialist task and must be carried out in compliance with current best practice, a useful guide to which is provided in the ICE, Site Investigation Steering Group Report on "Site investigation in construction" (Anon, 1993b). Part 4 of this document, "Guidelines for the safe investigation by drilling of landfills and contaminated land", is particularly relevant.

Summary recommendations concerning gases, toxic leachates and similar hazards associated with landfill sites are presented in Chapter 12.

11 Water resources and flooding

Introduction

The use, management and development of water resources have played a significant role in the development of the District. The groundwater and surface water in the urban area of Bradford and outlying towns has been subject to the threat of pollution since before the industrial revolution and from a wide range of sources since. Flooding of the valleys of the River Aire and Bradford Beck has, historically, been a major problem and considerable expenditure on remedial measures has occurred over recent years.

The wells and springs of the District have provided water for drinking, power and manufacturing since the Middle Ages. Pollution problems arose during the 19th Century due to the shortage of sewers in urban Bradford and the consequent lack of control of discharge of foul water and waste. In addition, the poorly controlled industries of those times have left a legacy of contaminated and damaged land and water, as in all other urbanised coalfield areas in Great Britain. Considerable improvements have been made subsequently in control of development, industrial practices and improvement of the ground and water.

The evolution of demands on the water resources present within, and transferred into, the District, make the need for resource planning of high priority. The main bodies involved in resource planning include the National Rivers Authority, Local Authority and Yorkshire Water plc.

The National Rivers Authority (NRA) has responsibility in relation to:

i) dealing with pollution incidents and prosecuting where an offence has been committed;

ii) catchment management planning and formulation of Catchment Action Plans with regard to water resource management, river flows, groundwater supply and protection, surface water quality, response to pollution incidents, flood defence and land use and development;

iii) carrying out aquifer vulnerability mapping and monitoring water quality;

iv) issuing and monitoring discharge consents;

v) surface water and groundwater abstraction licensing;

vi) liaison with and preparation of guidance for local authorities on flood defence, consent for structures in, and over, rivers, and on obstructions to water courses.

The Local Authority Planning Department is responsible for:

i) preparation of planning policies and development plans;

ii) control of development;

iii) taking action on environmental health issues.

Yorkshire Water Services is responsible for:

i) formulation of a water supply policy;

ii) providing a response to NRA and efficiency scrutiny.

Internal Land Drainage Boards for South Wharfe and Airedale are responsible for:

i) development and maintenance of local drainage networks (non-main rivers), usually through liaison with NRA and MAFF.

The main features relating to water resources in the District are presented on Map 8 and summarised on Figure 24 (*see* rear of book). The map provides information on the distribution of significant aquifers, main areas of aquifer recharge, areas of washland, the location of licensed groundwater abstraction sites, location of the main surface reservoirs and major geological faults.

Water resources and supply

Surface water

Yorkshire Water Services rely wholly on surface water sources for public water supply for the District. Most of this supply comes from reservoirs, though Yorkshire Water Services have a number of licensed spring sources and also significant quantities of water are abstracted from the River Wharfe at Lobwood, for supply to Bradford and Keighley, and at the Hollins, to supply Ilkley. The use of surface reservoirs in upland catchments outside the urban centre and indeed the District itself, reduces the threat of pollution from many industrial activities. The surface water imports from the Wharfe and Nidd Valleys have played a major role in the water supply policy for the District. In addition, some small private domestic and agricultural demands, particularly in Addingham, Burley in Wharfedale, Haworth Ilkley, Oxenhope, Silsden, Steeton and Thornton areas, are supplied by shallow wells and springs. These small supplies are not subject to the same controls as public resources.

The District has a large number of springs, often discharging onto slopes where the groundwater flow in aquifer sandstones is interrupted by impermeable mudstones (Figure 25). Permeable drift deposits which contain impermeable clay beds may be associated with perched water tables. Spring supplies have been important in some parts of the District e.g. Manywells Spring [SE 072 356]. Ilkley has traditionally been supplied by spring sources on Ilkley Moor. The springs are also supplemented by the sinking of shallow boreholes. A noteable mineral water spring in Ilkley is at White Wells [SE 118 467], which supplied the Roman Bath in the town. Analysis of this spa water is provided by Burrel (1914).

Surface abstraction licences are granted by the NRA according to hourly, daily and annual abstraction limits, depending on the requirements of the user and the need to protect the water resources and supplies to existing licensees. The major surface water abstraction licences in

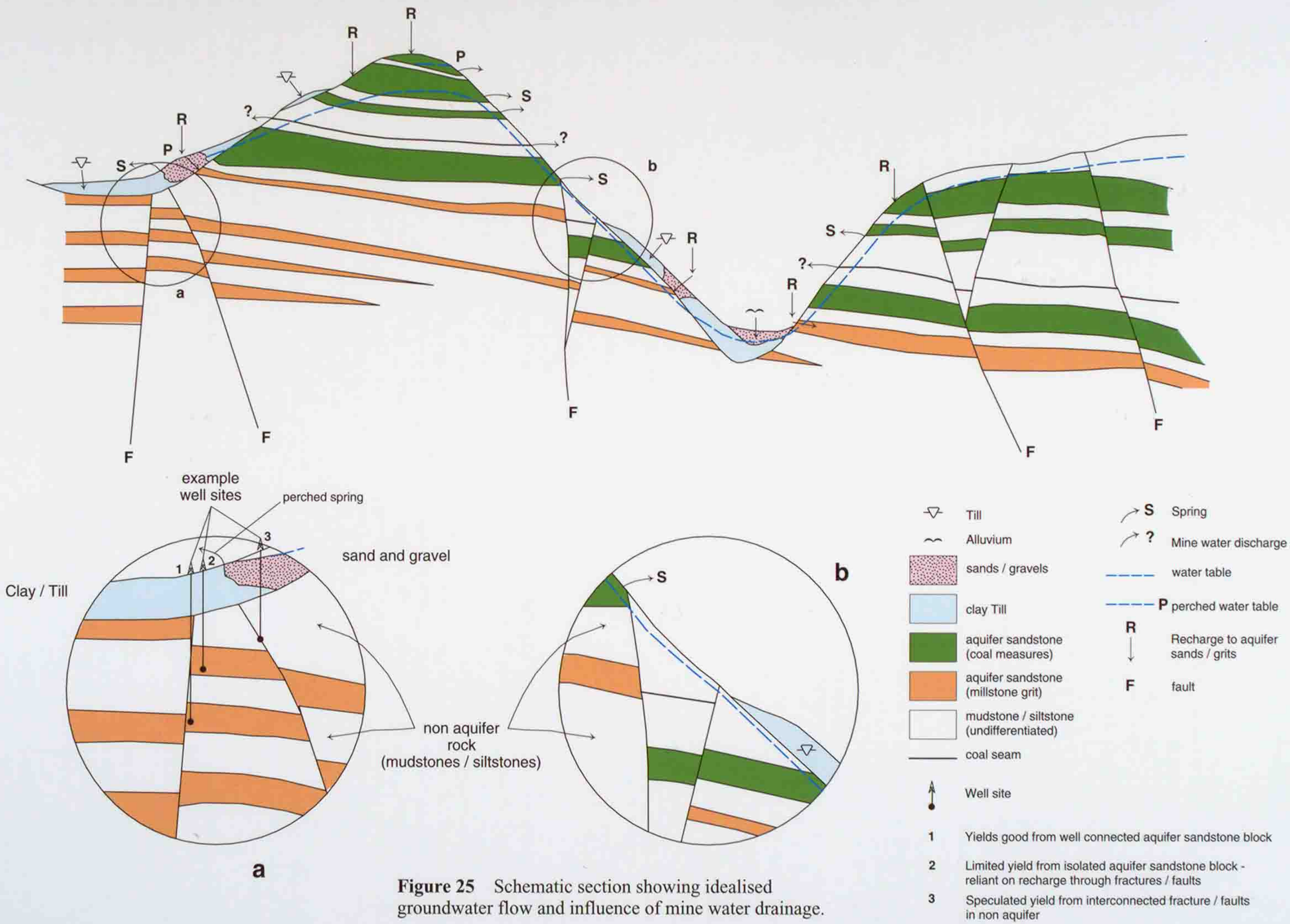


Figure 25 Schematic section showing idealised groundwater flow and influence of mine water drainage.

the area are mainly those of Yorkshire Water Services from reservoir and spring sources, which are as large as 6200 TCMA (thousand cubic metres per annum) at Thornton Moor Reservoir [SE 055 330]. Industrial cooling and processing licences up to 2.5 MLD (Megalitres per day) have been granted for sources in the District.

Surface water abstractions in the District from the Bradford and Keighley sub-catchments of the River Aire total 25 600 TCMA, of which approximately 75 per cent goes towards water supply. This is over 3.7 times greater than the groundwater abstractions in the same sub-catchment areas *(derived from NRA River Aire Catchment Management Data)*. More specific abstraction data are detailed in Appendix 14.3.

During the drought of 1995 Yorkshire Water needed to apply for a number of Drought Orders to maintain water supplies; particularly to authorise abstraction from the River Wharfe at low flows. In Bradford, stand-pipes were installed in preparation for supply restrictions in what has been described as an exceptionally severe drought. The threat of supply restrictions in Yorkshire is not completely new. The drought year of 1959 saw the Pennine springs run dry and standpipes in place and in 1976 standpipes were readied for use. Yorkshire Water Services were able to deflect much of the criticism arguing that the situation had a likely return period of 100 years (a frequency of one each century). The capital investment required to increase surface water storage, or other alternative water sources, for such infrequent events has seemingly been regarded as too great and unnecessary if successful responsive demand control and leakage repair actions could be taken as an alternative. However, in response to the recent drought, Yorkshire Water have started to lay pipelines to supply water to Bradford from the Leeds supply system.

Groundwater

There are no groundwater abstractions for public domestic supply in the District. This is due to the absence of major aquifers and the complex nature of groundwater flow and quality. However, abstractions for public supply from the Millstone Grit aquifers present just to the east of the District, in the Guiseley/Yeadon area, were particularly significant and are understood to have been regularly used by Yorkshire Water before pumping ceased in the 1970s. Abstraction for industrial purposes has a long history associated in particular with the textile industry. Although total useage has declined, industrial demands for groundwater continue.

Groundwater abstractions in the District are of the order of a quarter of the surface water abstraction. In the Keighley and Bradford sub-catchments of the River Aire, groundwater abstractions total 6900 TCMA, of which just 20 per cent goes towards water supply. In contrast almost 80 percent of groundwater is used in industrial processing *(derived from NRA River Aire Catchment Management Data)*. More specific abstraction data are detailed in Appendix 14.3

The main aquifers exploited in the District are the sandstones of the Millstone Grit and Lower Coal Measures. Within the Millstone Grit, the Rough Rock and Rough Rock Flags, Guiseley Grit and Woodhouse Grit are the most significant. Other sandstones, such as the Huddersfield White Rock, are less significant but do contribute to borehole yields and may yield greater amounts where adjacent to faults. Towards the north-west of the study area, on Skipton Moor, the Pendle Grit is locally significant as a domestic water source. The most significant of the Coal Measures aquifers is the Elland Flags, which ranges in thickness from 40 to 75 m. The Elland Flags crop out widely in the south-east of the District, including Bradford, Shipley and Thornton. Tables 3 and 4 (Chapter 6) provide information on the thickness and lithological description of the principal sandstones in the District.

Alluvial deposits in the Aire valley have been licensed for small groundwater abstractions. Glaciofluvial sands and gravels (indicated on Map 3) generally have high transmissivities, making them suitable aquifers. However, in the District these deposits tend to crop out in small, isolated deposits and would provide limited volumes of groundwater.

The thickness of drift in the Aire Valley has been recorded up to 55 m (see Map 3 and Figure 10), where Alluvium and River Terrace Deposits overlay a sequence of interdigitating Till, Glaciofluvial and Glaciolacustrine deposits. The distribution of clays within drift deposits are fundamental in limiting recharge to the aquifers. For the purpose of aquifer vulnerability mapping, a total clay thickness greater than five metres is considered effective in preventing water infiltration or 'recharge'. The type of the drift cover is important. Fractured clay or oxidised clay, greater than five metres thick, is sometimes assumed to allow recharge. For the purposes of this study a five metre drift thickness contour has been selected as the limiting thickness for recharge. The areas of limited recharge are indicated on the Water Resources and Flooding map (Map 8).

The complexity of faulting over much of the study area makes a regional assessment of groundwater flow patterns and contours of the groundwater level difficult. General strike trends of major faults are north-west to south-east, which are parallel to the major river valleys, with subordinate NE-SW trending faults (see Chapter 6). The significance of the faults, shown schematically on Figure 25, is three fold.

i) The faults can throw otherwise isolated sandstone layers together developing and extending the hydraulic connections between these layers.

ii) Displacement on large faults may result in isolation of sandstone aquifers, limiting the volume of interconnected aquifer.

iii) The faults may act as conduits extending the hydraulic radii of boreholes. Exceptional recorded transmissivities may be the result of the presence of faults, rather than a high hydraulic conductivity of the sandstone.

Evidence of fissure flow effects in boreholes is limited. However, the intrinsic permeability of the sandstones is unlikely to account for the high transmissivities reported by McGinily (1993) without contributions from the fissures reported in detailed drillers logs. The significance of fissures and faulting thus cannot be over-stated.

Only a limited number of samples of aquifer sandstones have been tested in the laboratory for porosity and permeability. These are available from the BGS Aquifer Properties Manual, a selection of which is reproduced in Table 18.

Some aquifer recharge may occur through mains water and sewerage leakage or shallow mine workings, particularly in the urban areas of Bradford. Some of this recharge may be associated with contamination of the groundwater.

Climatological data plays an integral part of catchment management and resource management strategies. The data provided by the Meteorological Office Rainfall and Evaporation Calculation System (MORECS) are based on complex calculations *(Penman-Montieth calculations)*

Table 18 Generalised groundwater data in District from the BGS Aquifer Properties Database.

Aquifer	Typical Porosity Range (%)	Intrinsic Permeability Metres/day	Typical Transmissivity (T) Range Metres^2/day	Notes
Elland Flags	10–15	10^{-4}	20–3200	Maximum T = 22 000
Rough Rock/ Rough Rock Flags	15–20	10^{-2}	40–150	
Huddersfield White Rock	10–15	10^{-4}	30–40	
Guiseley Grit	15–20	10^{-2}	20–300	Maximum T = 1800–4000 by bail test
Kinderscout and Pendle Grits	15–20	10^{-2}	N/A	Assume T similar to Guiseley Grit

developed by considering the weather, soil type and vegetation over 40 km^2 grids. MORECS grid squares 92 and 98 cover the District. The total rainfall distribution over the District ranges from 1400 mm yr^{-1} in the north-west to 700 mm yr^{-1} in the east of the District.

The *Effective Rainfall* which recharges aquifers in the District can be calculated by taking into account run-off, evaporation and the moisture content of the surface soils. In an average year (scaled for an average rainfall of 1000 mm), the effective rainfall in the District is approximately 450 mm. The monthly distribution of the effective rainfall is often as important as the annual amount of effective rainfall. In drought years such as 1990 and 1995, the monthly effective rainfall may be zero from April until September which means that aquifers recieve no recharge during those months.

A measure of the moisture content of soils is the *Soil Moisture Deficit*. This represents the amount of water expressed in millimetres (rainfall) required to wet a soil to a condition known as the "field capacity" of the soil, at which, excess water would normally drain freely under gravity. The *Potential Evaporation* is the measure of water loss from a surface by evaporation where the water supply is such that unrestricted evaporation occurs. The actual evaporation is always equal to or less than the potential evaporation because soil surfaces dry and limit the amount of water available for evaporation. The monthly rainfall infiltrating the surface must exceed both the potential evaporation and soil moisture deficit in order to recharge aquifers. In an average year in the District, the mid-summer soil moisture deficit is less than 60 mm, whilst in a drought year it is possible to exceed 100 mm.

Water Quality

Surface Water

In 1848 the passing of the Bradford Water Works Improvement Act empowered the corporation to cleanse the water courses in the District. The development of the Esholt sewage treatment works has played a considerable role in the improvement of the water quality of the River Aire and its tributaries. This development is chronicled in the publication, "City of Bradford Sewage Disposal 1870–1947" (Anon, 1947), which provides a comprehensive account of the transfer of sewage treatment facilities from Frizinghall to the existing Esholt site. Subsequently, there was rationalisation of the foul water services and the development of the Marley Sewage Treatment Works (STW), also on the River Aire, and STWs at Ilkley, Ben Rhydding and Burley Menston, on the River Wharfe. Some of the sewage from south Bradford is treated outside the District at North Bierley STW and is discharged to the River Calder catchment.

At present the monitoring of surface water quality is carried out by the NRA on the River Aire at the Sandoz chemical works site, at Calverly Bridge [SE 224 370], just outside the District. The siting of mobile river quality monitors downstream of the STW sites in the District is planned.

The General Quality Assessment (GQA) classifications of A (Good) to F (Poor) and the Statutory Water Quality Objectives (WQO) scheme are replacing the National Water Council (NWC) Classifications used by the NRA. The classifications are currently under development but are based on the same chemical properties. The Water Quality Objectives are defined as quality targets based on the uses of the river stretch. River Ecosystem (RE) classes will ultimately be established by legal notice for stretches of water courses and original National Water Council classes will be transformed accordingly within set time-frames.

The existing NWC Chemical River Water Quality classes are based on the criteria: Biochemical Oxyen Demand (BOD), Disolved Oxygen (DO) and ammonia. The classes are ranked in order 1A, 1B, 2, 3, 4, as described below.

1A	Very Good	Waters of high quality suitable for potable supply abstractions.
1B	Good	Waters of less high quality than 1A, but usable for substantially the same purposes.
2	Fair	Waters suitable for potable supply after advanced treatment.
3	Poor	May be used for low grade industrial abstraction.
4	Bad	Waters which are grossly polluted and are likely to cause nuisance.

Biological River Water Quality standards are also applied to river catchments. These follow the same classification as above, and are based on the presence and abundance of invertebrate life in the water. Much of the River Aire is classified as fair or poor and Bradford Beck at Shipley is classified as bad. The River Wharfe has a classification of good or very good.

The establishment of River Quality Objectives are related to the land use along stretches of water within catchment areas. The classification is the same as that for the River Water Quality. The comparison of the objective values and actual values highlight stretches of water where efforts to improve water quality can be concentrated.

The Leeds–Liverpool Canal has a NWC water quality class of fair from Keighley to Bradford and good from Bradford towards Leeds. The NWC quality objective is a classification of good, throughout the District.

A number of factors influence the surface water quality in the District, many of which are discussed further in Chapter 6. These include:

- Combined Sewage Outflows (CSOs) and sewage treatment works (STWs) represent the most significant potential pollution sources of surface water courses, particularly when CSOs are defective. A substantial investment in the sewage system in central Bradford including waters from Bradford Beck and Westbrook has been undertaken in the last four years, half of which was funded by the European Regional Development Fund (ERDF) and European Social Fund (ESF). This complements substantial investment by Yorkshire Water plc on the early stages of a Bradford sewerage rehabilitation strategy anticipated to cost £ 80 million. The system has two branches, a maximum tunnel diameter of 3.7 m and a maximum capacity of 44 m^3s^{-1}. The capacity is similar to a peak flow rate achieved twice each century and equivalent to almost three times the high flow rate of the River Aire at the western edge of the District.

- The textile industry has, historically been a major polluter in the District, especially in Bradford Beck, through wool washing producing effluents with soaps, lanolin oils, in addition to problems associated with bleaching and dyeing. More recently pollution of waterways with permetherin (a textile insecticide) and the drin-group insecticides has become a problem.

- Other industrial pollution, both historical and modern, has been a problem, particularly of Bradford Beck. At East Brook Beck, in Bradford, levels of dissolved zinc exceeded the environmental quality standard (EQS). This has been assumed to be a result of leaching from contaminated land. Spen Beck was seriously affected by industrial contamination following a fire in July 1992 at Allied Colliods.

- Oil and gas contamination from former tar pit leachate. The sites of former gas works are traditionally associated with a complex cocktail of pollutants. Bradford Beck has been identified as having elevated levels of pollutants consistent with a source from sites producing town gas. The threat from Non-Aqueous Phase Liquids (NAPL) pollutants is detailed below.

- Landfill operations and particularly problems associated with leachates from old sites in which tipping was uncontrolled and little attempt was made to prevent pollution migration. The quality of Spen Beck at the southern edge of the District is affected by the Odsal Tip, but disharges to the south of the District into the River Calder.

- Colliery spoil and abandoned colliery mine workings may contribute discharges of acid, ferruginous water, which may also include elevated levels of manganese, aluminium and sulphates.

Water Quality issues affecting the District, but originating from outside, include fish farm waste, STWs, CSOs and the seasonal variation in sewage loading due to tourism.

Groundwater

The quality of groundwater from the Millstones Grit aquifers has traditionally been recognised as better than that from the Coal Measures. The groundwater quality of the aquifers in the adjacent Leeds District was studied by Marsland (1975), who identified a deterioration of quality with path length down dip, to the south, presumably due to an increase in contamination from urban sources as the aquifers extended beneath the city. More recently, McGinily (1993) undertook sampling from industrial abstraction points within the Bradford urban area. He analysed Bradford and Leeds hydrochemical data, summarised in Table 19, and proposed basic hydrochemical contours for the major ions. The groundwater levels followed the general groundsurface relief with flow directions roughly toward the north, parallel to the surface flow of Bradford Beck. Standing water levels are in the order of 10 m below ground level, in a band approximately 0.5 km wide, either side of and parallel to Bradford Beck.

Table 19 Typical chemistry of groundwaters in Coal Measures and Millstone Grit aquifers (McGinily, 1993).

	Coal Measures	Millstone Grit
Total Dissolved Solids, mgl^{-1}	400–600	200–300
Hardness mgl^{-1}	200–500	100
Chloride (as Cl^-), mgl^{-1}	<100	<100
Sulphate, mgl^{-1}	>100	25–100
Iron, mgl^{-1}	0.5–5.0	<1.0

A number of hydrochemical processes affect the quality of groundwater in the District. The significance of cation exchange in the process of natural water softening has been recognised. This involves the replacement of calcium, in solution, with sodium ions. The development of the textile industry, in and around the District, often featured the sinking of deep boreholes through the Coal Measures to reach Millstone Grit aquifers, where the water was naturally softer and suitable for wool washing processes.

Specific polluting practices include are described below:

Landfill Operations

The legacy of uncontrolled solid waste tips and generation of harmful leachates is a serious issue, discussed further in Chapter 12. The location and risk assessment of former tips has been a focus of the work of Local Authority pollution control officers. The cost and risk rating assessments of proposed landfill sites in the District have been based on an assessment by the Waste Regulation Authority of permeability of the containing medium, presence of water within the site, the importance of water resources and proximity to mine workings. The Waste Regulation Authority require extensive reviews and site investigations prior to passing landfill applications and may require containment structures and barriers as part of a leachate management and monitoring programme. The NRA may act as statutory consultees to the Waste Regulation Authority on issues of landfill applications. The issue of rising groundwater levels has implications for landfill leachate generation, particularly for old waste sites.

Acid Mine Drainage (AMD)

Coal seams were formerly worked at outcrop and at depth, principally in the south and east of the District (see Chapter 8 and Map 5). The influence of mining includes increased groundwater flow rates through open shallow workings and the presence of mining subsidence, which may have developed or enhanced existing fractures in the rocks overlying worked coal seams. The resultant increase in the vertical hydraulic conductivity may enable minewater to migrate upwards through otherwise impermeable bedrock, providing that a sufficient driving head is applied, for instance by the overburden of confining layers or drift cover.

The effect of rising groundwater levels in former mining areas is an important current hydrogeological issue in the UK. When water floods oxygenated mine workings, it is likely that oxydised pyrite will be taken into solution, forming sulphuric acid. The lowering of the pH of the solution can result in increased mobility of polluting metals, such as iron and aluminium. Minewater may also become polluted with organic compounds derived from spills of lubricating and hydraulic oils underground. The term 'acid mine drainage' (AMD) is used to describe the subsequent discharges. An initial highly ferruginous discharge is usually associated with the cessation of mine dewatering. The local groundwater level 'rebounds' filling the worked cavities or subsurface 'ponds' until at a higher level these discharge at topographic low points, often displaying tell-tale ochreous characteristics. The initial pulse of high concentration generally declines and with time it is more likely that seasonal variations in the water table position regulate the process. A similar situation is likely to occur where naturally rising water levels flood former mine workings or mine spoil tips. Robb (1994) summarises the processes involved in the formation of AMD.

AMD is not a major issue in the District, where mining ceased during the early part of this century. Groundwater levels would have risen subsequent to the cessation of pumping, but are unlikely to be still rising. Most mine discharges are now stable, but may `flush up' during seasonal fluctuations in groundwater level. There have been reports of ferruginous discharges in the Riddlesden area, possibly associated with old coal workings in the Morton Banks Coal. The actual reason for the discharges is uncertain. There are likely to be other locations where a rise in groundwater level could discharge AMD, particularly in the Bradford and Shipley areas.

Industrial and domestic water supplies have been derived from coal mine dewatering in the UK. Without a comprehensive study of the quality and implications of pumping former mine sites it is unlikely that using water pumped from previous mine workings could be considered in the Bradford District without a major study of the effects of the abstactions.

Non-Aqueous Phase Liquids

The threat posed by many synthetic organic chemicals on groundwater supplies represents one of the most urgent hydrogeological issues. The use of these compounds as concentrated liquids in industrial areas is widespread (Eastwood et. al. 1991). If they are spilled, the low water solubility of some of the liquids may mean that they become resident in the subsurface as Non-Aqueous Phase Liquids (NAPLs).

The NAPLs can enter the subsurface environment as the result of leakages from underground storage tanks or land disposal sites, accidental spillages, or improper disposal. NAPLs are classified into light non-aqueous phase liquids (LNAPLs), which include petroleum and diesel fuels and denser than water liquids (DNAPLs), amongst which the halogenated solvents (which include the chlorinated solvents) are the most frequently occurring (Folkard, 1986, Foster and Lawrence, 1992).

Chlorinated solvents have physicochemical properties which make them particularly insidious groundwater pollutants. The permitted concentration of many DNAPL compounds in drinking water is very low (in the parts per billion (ppb) range). However, these compounds are usually sufficiently water soluble to exceed these low limits, and thus pose a serious threat to groundwater quality. Where NAPLs are present in an aquifer they represent a subsurface source of the pollutant. Slow dissolution by flowing groundwater produces a plume of the aqueous phase contaminant which extends down groundwater gradient of the pollution source. Given the slow rates of dissolution in groundwater, such subsurface residual sources could persist for decades.

The precise depth and rate of movement depends both on the characteristics of the aquifer and the properties of the liquid. In the case of the halogenated solvents, which have low viscosities and densities significantly greater than groundwater, rapid and deep penetration of aquifers largely independent of the hydraulic gradient can be anticipated (Mackay et al., 1985). This is particularly likely when the aquifers are fissured. Pools of DNAPL may collect above less permeable horizons within or at the base of the aquifer. During downward movement of DNAPL through the aquifer, some of the liquid will be retained as discontinuous droplets isolated within the pore space of the rock as a residual phase (Schwille, 1988). The residual phase is considered to form the most significant component of the subsurface pollution, greater than DNAPL pools (if present), aqueous, sorbed or gaseous phases.

DNAPL pollution is likely to be complex. Once an aquifer has become contaminated by DNAPL it is likely to remain so. The remedial measures currently available, such as 'pump and treat', are ineffective due to the slow dissolution of the non-aqueous phase and inaccessibility of the source to mobile groundwater, with consequent slow migration to pumping sources.

Groundwater Vulnerability

The NRA Policy and Practice for the Protection of Groundwater (1992) has provided a framework for the protection of individual groundwater sources and the groundwater resource as a whole. The policy involves the delineation of groundwater protection zones (GPZs) for all groundwater sources which are licensed to abstract more than 1 Mld^{-1}. The policy details the restrictions applicable to certain practices within the specified zones.

A series of fifty three Groundwater Vulnerability maps, at 1:100 000-scale, covering England and Wales, are being produced for the NRA by the British Geological Survey Hydrogeology Group and the Soil Survey and Land Research Centre, Cranfield University, as a componant part of the NRA PPPGW. The Bradford District will be covered as part of map 11 of the series in 1996/7. In total, the maps will indicate the spacial distribution of six vulnerability classes.

1. Geological classification (3 types)

- Major Aquifers — Highly permeable formations usually with a known or probable presence of significant fracturing. These may be highly productive and able to support large abstractions. None are defined in District.

- Minor aquifers — Can be fractured or potentially fractured rocks which do not have a high primary permeability, or formations of variable permeability including unconsolidated deposits. These will not produce large quantities of water for abstraction but are important for local supplies and in supplying base flow to rivers. In the District, this category includes the Millstone Grit and Coal Measures and drift deposits (landslips, Alluvium, Alluvial Fan Deposits, River Terrace Deposits, Glaciofluvial sand and gravel deposits.

- Non Aquifers — Formations that are generally regarded as containing insignificant quantities of groundwater. However limited flow does take place and needs to be considered when assessing the risk associated with persistent pollutants. Non aquifers have not been differentiated in the Bradford District.

2. Soil Classification (3 types and 7 sub-classes)

Three soil types of high, intermediate and low leaching potential are identified. These have sub-classes based on individual soil characteristics. The soil types are based on soil physical and chemical properties which affect the downward movement (leaching) of water and contaminants. These include texture, structure, soil water regime and the presence of distinctive layers such as peaty topsoil or rock and gravel at shallow depth.

- Soils of High Leaching Potential

  H1 Soils which readily transmit liquid discharges because they are either shallow or susceptible to rapid by-pass flow directly to rock, gravel or groundwater.

  H2 Deep permeable coarse textured soils which readily transmit a wide range of pollutants because of their rapid drainage and low attenuation potential.

  H3 Coarse textured or moderately shallow soils which readily transmit non-absorbed polutants and liquid discharges but which have some ability to attenuate absorbed pollutants because of their large clay or organic matter contents.

  U Soil information for urban areas is less reliable and based on fewer observations than in rural areas. The worst case is assumed and such land is classified as of high leaching potential unless proved otherwise.

- Soils of Intermediate Leaching Potential

  I1 Soils which can possibly transmit a wide range of pollutants

  I2 Soils which can possibly transmit non or weakly adsorbed pollutants and liquid discharges but are unlikely to transmit adsorbed pollutants

- Soils of Low Leaching Potential

  L Soils in which pollutants are unlikely to penetrate the soil layer because either water movement is largely horizontal, or they have the ability to attenuate diffuse pollution. They generally have a high clay content.

Other Issues

Flooding

The rivers Wharfe and Aire dominate the drainage of the northern and central parts of the District, respectively, both flowing generally toward the south-east. The main source of Aire and Wharfe baseflow water are Carboniferous aquifers in the Skipton area, to the north-west of the District. A number of tributary streams, known locally as becks, have baseflows derived from the Coal Measures and Millstone Grit sequences. Part of the southern boundary of the region is delineated by becks belonging to the catchment of the River Calder, e.g. Spen Beck, Clifton Beck and Red Beck. Bradford Beck is the main stram running through Bradford city centre.

Flooding has long been a serious issue in the District. Bradford Beck has suffered 15 serious floods since 1763 (Gilligan, 1908). A particularly severe storm in September 1824 resulted in considerable erosion in gulleys in the Stanbury area, with floodwaters heavily charged with mud, peat and boulders. These floodwaters caused considerable discharge of peat into the River Aire, with a resultant reduction in water quality. The development of reservoirs in many of the valleys in the west of the District during the mid-19th Century probably had the effect of delaying the flow of floodwaters into the Aire and reducing the amount of suspended material reaching the major rivers. However, such flood events may transport such large volumes of suspended material that the volume of reservoirs may be significantly reduced as time passes.

The effects of a further damaging storm to the north of the District on Barden Fell, in June 1908, are recorded in detail by Gilligan (1908) There are records of serious events in September 1946 and May 1947, and more recently floods in 1962 and 1982 caused complete disruption of the city centre (Wallis, 1992).

The characteristic V-shaped valleys of the tributary becks result in a rapid response to rainfall or 'flashy' flow regime for the catchments. This regime is indicated by the Base Flow Index (BFI), which is a means of indicating the component of river run off that is derived from stored groundwater sources as baseflow. The BFI ranges from near to zero for very infrequent and intermittent streams with a low catchment storage, to near 1 where consistent

Table 20 Hydrological data from three guage stations on the principal rivers in the District (from NRA Catchment Plans).

River	Wharfe	Aire	Bradford Beck
Location of guage station	Addingham [SE 092 494]	Kildwick Bridge [SE 013 457]	Shipley [SE 151 375]
Mean discharge	14.5 m^3s^{-1}	6.2 m^3s^{-1}	0.6 m^3s^{-1}
Catchment area	427 km^2	282 km^2	58 km^2
Base flow index (BFI)	0.33	0.37	0.48
Average dry weather flow (95% exceedance parameter)	1.54 m^3s^{-1}	0.50 m^3s^{-1}	0.14 m^3s^{-1}
Average high flow measure (10% exceedance parameter)	35.0 m^3s^{-1}	15.7 m^3s^{-1}	1.2 m^3s^{-1}
Peak recorded flow (date) [Period of record]	552.6 m^3s^{-1} (8 March 1979) [1974–90]	98.1 m^3s^{-1} (5 December 1972) [1968–90]	34.3 m^3s^{-1} (21 March 1984) [1983–90]

base flow from storage represents the bulk of the total flow. A river in a catchment of impermeable bedrock or drift is likely to exhibit a BFI of less than 0.35, whereas rivers in a permeable catchment may exhibit a BFI of 0.9 (Institute of Hydrology Report 108, 1992). Values of BFI for the District, shown in Table 20, range from 0.33 to 0.48.

The River Aire and River Wharfe are prone to flooding onto washlands, the distribution of which are indicated on the Water Resources and Flooding Map (Map 8), and include:

River Wharfe: Scattered between Addingham and Gill Beck
River Aire: Major engineered washlands in broad plain around Keighley/Kildwick and scattered washland tracts elsewhere.

The NRA catchment management plans identify washland areas and classify riverside land use and the expected frequency (event per return period) of flooding on a scale from A to E, where A represents highly populated urban areas with a return period of 50–100 years and E represents agricultural land of limited interest which has a return period of less than 2.5 years. This distribution of the land use classification along the River Aire and part of the River Worth is published in the River Aire Catchment Management Plan.

The Bradford Beck flood alleviation scheme is a 2.15 km storm flow diversion to the north of the city costing £12 million. The Ministry of Agriculture, Fisheries and Food (MAFF) and Yorkshire Water plc also contributed funding. However, flood defence facilities have been identified as insufficient at the following locations:

Aire: Shipley, Bingley and upstream of Keighley
Wharfe: Addingham, Ilkley and Burley

Flood Warning systems are in operation in the District. On the River Aire flood warning stations are at Kildwick, Keighley, Bingley, Cottingley and Shipley. The uprating of flood-forecasting using the regional telemetry system and river flow modelling such as rainfall response and snowmelt studies will improve the forecasting. Hydrological data for three guaging stations present on the rivers Wharfe, Aire and Bradford Beck are summarised in Table 20.

Low river flow levels, particularly during drought years, may also pose a problem to aquatic life in rivers and maintenance of wetland habitats. The River Worth has compensation flows from impounding reservoirs within the District. The River Wharfe has controlled releases from Grimwith, North Yorkshire [SE 060 645] to augment flows for abstraction near Ilkley Treated sewage is later returned to the River Aire, thus augmenting flow. Most of the water released in the River Aire at Esholt STW has come from the Nidd and Wharfe catchments.

Rising Groundwater

Groundwater levels in central Bradford, as in Leeds, may have risen in response to decreased abstraction (Lake et al., 1992), though as groundwater levels are not monitored within Bradford's urban district this can not be verified. A monthly record for the national groundwater level archive is made at Silsden Lower Heights Farm (SE 029 479) in the Millstone Grit of the north-west of the District.

Between 1948 and 1965, major industrial abstractors were required to return abstraction and groundwater level records as part of their abstraction consents. The actual abstraction data is still collected by the NRA, but is no longer publicly available. However, the trend in total groundwater abstraction can be inferred from licences remaining (Appendix 14.3) or from licences revoked.

Annual rest water level data has been used in cities such as London and Birmingham to indicate rising groundwater levels (Knipe et al., 1993). A similar study in the centre of Bradford would be useful to identify if rising groundwater levels is an issue. However, the reliability of determinations of rest groundwater level at large abstraction sites can be questionable. If insufficient time is allowed for groundwater level recovery when pumps have been switched off, the recorded levels may indicate rest water levels deeper than is actually the case. For higher transmissivity aquifers exploited by industry in Bradford this is less important as recovery should generally be rapid.

Summary and recommendations

Public water supply to the District is wholly dependent on surface water sources, mainly from reservoirs and river abstractions, both within and outside the District, and from licensed spring sources. In addition, some small private domestic and agricultural demands are supplied by shallow wells and springs. These small supplies are not subject to the same controls as public resources. Public water supplies have generally been able to meet demand, though during exceptional drought years there have been threats of supply restrictions.

There are no major groundwater abstractions for public domestic supply from aquifers in the District, though supplies from the Millstone Grit aquifers to the east of the District were formerly significant. Groundwater abstraction for industrial purposes, particulary for the textile industry, continues to be of importance, though total useage has declined over recent decades. The main aquifers exploited in the District are the sandstones of the Millstone Grit and Lower Coal Measures. Areas of thick, impermeable drift deposits, particulary in Airedale and Wharfedale limit recharge to the aquifers. For the purposes of this study, a thickness of five metres of impermeable drift has been selected as the limiting thickness for recharge. The complex pattern of faults present in the District are considered to have a great significance to current and potential supply of groundwater. They may result in hydraulic connection or isolation between sandstone aquifers and may also act as conduits extending the hydraulic radii of boreholes.

A substantial effort has been made over recent years to improve the quality of water from sewage treatment works in the District. This has been supported by a major capital investment in new storm sewers and combined sewer overflow systems and the promotion of more regulated discharges of trade effluents. These developments should improve not only water quality but also reduce the incidence of flooding in the District.

The main factors which may potentially influence surface water quality in the District include combined sewage outflows and sewage treatment works, effluents from textile mills and other industrial pollution, contamination from former gasworks sites, leachates from old landfill operations and discharges of acid ferruginous water from abandoned colliery mine workings

The main factors which may potentially influence groundwater quality in the District include harmful leachates from old landfill sites, in which the tipping of waste was uncontrolled and no measures were employed to prevent leachate migration, from potentially contaminated industrial sites, and acid mine drainage from disused colliery workings. The presence of Non-Aqueous Phase Liquids which include petroleum and diesel fuels and halogenated solvents, such as chlorinated solvents, are a particular concern. Given their slow rates of dissolution in groundwater, such contaminants could persist for decades. In the case of halogenated solvents, once an aquifer has become contaminated it is likely to remain so. The remedial measures currently available, such as 'pump and treat', are ineffective in treating such pollution.

Flooding has long been a problem in the District. Controlling of water discharges through the construction of reservoirs reduced the problem during the 19th Century. However, continued development on flood prone areas has exacerbated the problem and has required considerable investment in flood defence schemes. A policy of protection of washland areas from development should ensure that the risk of flooding is not increased in the future.

The following recommendations relate to water supply and the issue of flooding.

1. An underlying principle of water supply policy in the District is that the upland surface reservoirs are not regarded as particularly vulnerable to pollution. However, their significance in both water supply and river regulation will ensure that these remain the focus of water resource development and the delineation of catchment protection zones for surface reservoirs should accordingly be a priority.

2. Water supply problems have become an increasingly important issue in the District. In the short term, the problem may be overcome by demand control and leakage repair, though major capital investment to provide water from the Leeds system is underway. Construction of new reservoirs, both within and outside the District is likely to be unacceptable. However, increasing the volume of existing reservoirs may be achieved by regular dredging of sediments and top-up supplies from groundwater sources may be a suitable method of overcoming emergency shortages in supply.

3. The NRA Policy and Practice for the Protection of Groundwater (1991) has provided a framework for the protection of individual groundwater sources and the groundwater resource as a whole. The tightening of practice restrictions for surface and groundwater abstraction locations should be supported.

4. Particular attention should be paid to the threat posed by potentially contaminated industrial sites. In particular many synthetic organic chemicals may become resident in the subsurface as Non-Aqueous Phase Liquids as the result of leakages from underground storage tanks or land disposal sites, accidental spillages, or improper disposal. Every attempt should be made to ensure that strict controls on the storage of such chemicals are enforced.

5. Flood defence facilities have been identified as insufficient along stretches of the Rivers Aire and Wharfe and continued investment in new defences is required. Protection against development of washland areas within Airedale and Wharfedale needs to be rigorously enforced to ensure flood defence measures taken in the urban areas of Bradford remain effective.

6. Little information is available on the nature of groundwater levels in the District. A study in the City of Bradford would be useful to identify whether there are rising groundwater levels.

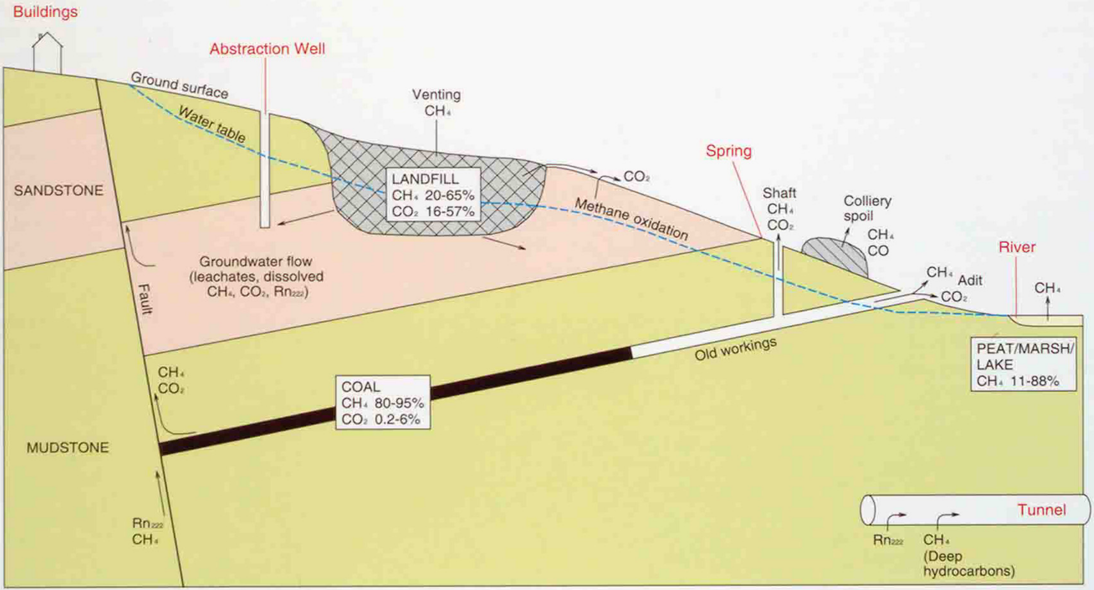


Figure 26 Schematic section showing idealised migration of gases and leachates from landfill sites and gases from disused mine workings.

12 Gas emissions and leachates

Introduction

This chapter discusses the sources and nature of gas emissions and leachates, factors affecting their migration and accumulation, identification of areas of susceptibility to these potential hazards and indicate types of remedial measures. The main potential gas hazards are associated with the incursion of methane, carbon dioxide and radon gases into buildings and engineering works, such as tunnels, and the formation of toxic leachates derived from landfill sites and other areas of man-made deposits (Figure 26). The significance of these gases is described separately.

When water is contained in, or percolates through, material containing contaminants it may dissolve or carry some of these. Some leachates may be toxic or otherwise harmful to humans, animals or plants. Leachates may be associated with landfill sites or other areas of man-made deposits (Table 6, Chapter 6).

Methane

Methane (CH_4) is a colourless and odourless flammable gas, most commonly produced by the anaerobic degradation of organic material (Hooker and Bannon, 1993).

Source of gas

Methane is derived from the decomposition of plant material, biodegradable refuse, coal and carbonaceous shales, including marine bands and from mine spoil tips, rich in discarded coal. It occurs in a free state in pores and cavities, adsorbed onto coal cleat, and in solution in groundwaters.

i) Mine Gas

An important source of this potential hazard is the migration of methane from former coal mine workings, where it is often referred to as `firedamp'. Coal tends to act as a reservoir for methane, which typically forms 80-95% of the total volume of gases present (Williams and Aitkenhead, 1991; Table 1). However, methane tends to be released only when coal is disturbed, either by geological disturbance, such as faults (Robinson and Grayson, 1990) or by mining disturbance (Creedy, 1990). Naturally occurring methane may also be produced by the degradation of organic shales and occur as dissolved gas within groundwaters.

Colliery spoil with high coal contents (in excess of 20% coal by weight) may be a source of methane, though combustibility of granular coal content is generally more of a problem than methane ignition (see Chapter 10).

Areas of coal workings are generally limited to the south-east of the District, including areas of urban Bradford, though localised areas of workings in Millstone Grit coals are present in the vicinity of Keighley and Stanbury (see Chapter 8 and Map 5).

ii) Hydrocarbon gas

Marine sediments rich in micro-organisms may produce thermogenic methane and oil following burial, compaction and heating. No surface emissions of hydrocarbon oil have

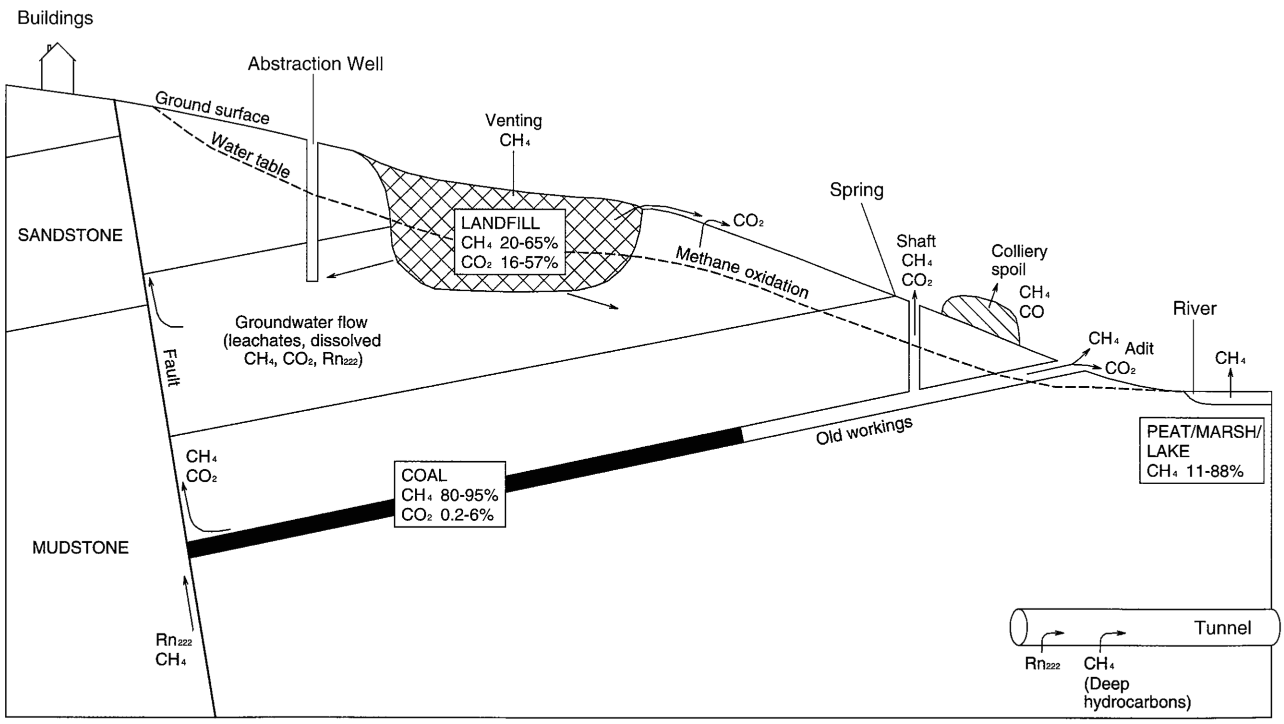


Figure 26 Schematic section showing idealised migration of gases and leachates from landfill sites and gases from disused mine workings.

been recorded in the District, though their presence at depth cannot be discounted.

iii) Landfill gas

Bacteriological methane can be formed by the biodegradation of organic matter in landfill sites under anaerobic (oxygen-poor) conditions. Landfill sites represent the most important source of methane in the UK. Methane makes up about 60%, though varying from 20 to 65%, of the volume of typical landfill gas (Williams and Aitkenhead, 1991). Methane has a lower density than air and has the potential to migrate from the landfill site, both vertically or laterally. Over the last 50 years there has been a marked change in the composition of landfill wastes, particularly with an increase in the volume of biodegradable material such as paper, and decrease in the content of ash; the introduction of the 1965 Clean Air Act has led to less organic wastes being incinerated. Hence, newer landfill sites tend to produce greater volumes of gas. Details on landfill gas characteristics and generation are given by Leach and Goodger (1991), Hooker and Bannon (1993) and in Waste Management Papers No. 26 and 27 (Department of the Environment, 1986 and 1989). Also, over recent decades there has been a change in the nature of landfill practice toward engineered containment with large sites in which material is densely packed and contained by impermeable barriers, with use, or venting, of gas (Williams, 1980). This permits exclusion of oxygen from the interior of the landfill, facilitating anaerobic conditions suitable for bacteriological degradation of organic material. However, such sites are likely to have reduced penetration of water through the waste, with a resultant decrease in rates of organic degradation. In such sites, methane and carbon dioxide generation may occur over many decades. Other sites, usually not contained or vented, present a possible greater risk from gas or leachate migration.

iv) Marsh gas (Wetland environments)

Further sources of bacteriological methane include areas of marshes and swamps, peatlands, lakes and man-made reservoirs, including mill ponds associated with the textile industry in Bradford. Such wetland environments usually produce a gas comprising 11–88 volume % methane (Williams and Aitkenhead, 1991).

Nature of hazard

Methane is a potential hazard in civil engineering and tunnelling operations, water abstraction boreholes, landfill sites, coal and mineral mining and construction in areas of former landfill sites or areas of contaminated land (Hooker and Bannon, 1993). The potentially serious implications of a methane hazard are demonstrated by a number of recent events. An explosion at Loscoe, Derbyshire, in March 1986, provides an important case study for the problems associated with methane derived from landfill sites (Williams and Aitkenhead, 1991). Surface emissions of mine gas were discovered in 1988 to be affecting 54 properties in the former mining town of Arkwright, Derbyshire. Following initial evacuation of the affected properties and venting of old coal workings, the settlement was eventually relocated. The explosion in the Wyresdale tunnel, Abbeystead in May 1984, resulted from the presence of dissolved methane in groundwaters subject to hydrostatic pressures, which de-gassed into the tunnel subject to lower atmospheric pressures (Health and Safety Executive, 1985). At Abbeystead, the methane was probably generated from the degradation of carbonaceous shales, and was not associated with coal mining. The hazards associated with methane have also been recognised in the District, with archives recording a gas explosion in a demineralisation plant above a water borehole at Bradford Power Station [SE 1634 3398]. All Millstone Grit and Coal Measures strata in the District should be treated as potentially containing dissolved methane in the groundwater.

The main hazards, described by Hooker and Bannon (1993), are:

i) Methane forms an explosive mixture with air when in a concentration of between 5 volume % (the Lower Explosive Limit) and 15 volume % (the Upper Explosive Limit). This gas is particularly hazardous when in confined areas in which the gas can accumulate with sufficient air to form a flammable mixture;
ii) Although of low toxicity, methane may be an asphyxiant, due to the displacement of oxygen. Symptoms of oxygen starvation are evident at about 33 volume % methane, whereas a concentration of 75 volume % is fatal within minutes;
iii) High concentrations may cause vegetation die back as a consequence of oxygen starvation;
iv) Methane is one of the main contributors to 'greenhouse gases' in the atmosphere.

Carbon dioxide

Carbon dioxide (CO_2) is a colourless, odourless, non-combustible gas which is very soluble, forming a potentially corrosive carbonic acid, H_2CO_3. The gas has a high density, relative to air, and tends to accumulate in low areas.

Source of gas

Carbon dioxide is a naturally occurring gas in the atmosphere. Higher than normal concentrations of carbon dioxide may result from the oxidation or combustion of organic materials, such as methane and coal, both from *in situ* coal and colliery spoil. 'Blackdamp' is a combination of carbon dioxide and nitrogen, commonly present in disused workings and shafts. Carbon dioxide to methane ratios (%) from mine sources are typically less than 10%. Carbon dioxide is a major component of landfill and sewage derived gases. Bacteriological carbon dioxide can be formed by the biodegradation of organic matter in landfill sites under anaerobic (oxygen-poor) conditions. Such conditions are particularly a problem with newer, large landfill sites in which material is densely packed. Carbon dioxide makes up about 40% of the volume of typical landfill gas, though typically varies from 16-57% (Williams and Aitkenhead, 1991). Carbon dioxide to methane ratios (%) from landfill sources are typically greater than 30%. Carbon dioxide may also be produced by the action of acids on limestone aggregates, such as used in drainage blankets.

Nature of hazard

The main hazards, described by Hooker and Bannon (1993) and Appleton (1995), are:

i) At high concentrations the gas is toxic. The long term exposure limit is 0.5 volume %, the short term exposure limit is 1.5 volume %. Concentrations of 22 volume % are likely to be fatal. Physiological effects are very rapid;
ii) Carbon dioxide is denser than air and may accumulate in depressions, such as trial pits, displacing air, resulting in the potential of asphyxiation;

iii) High concentrations are toxic to plants and may cause vegetation die back;
iv) Carbon dioxide is one of the main contributors to 'greenhouse gases' in the atmosphere.

Other non-radiogenic gases

Other, potentially hazardous gases include carbon monoxide (CO), hydrogen sulphide (H_2S) and hydrogen (H_2). Details about these gases are provided by Hooker and Bannon (1993) and Appleton (1995).

Carbon monoxide

Carbon monoxide is a colourless, odourless and tasteless gas, produced by the incomplete combustion of organic material. The gas may form after explosions of flammable gas or coal dust, or from the simple oxidation of coal, either *in situ* or present within colliery mine waste. The gas is explosive in air in the range 12 to 75 volume %. The gas is highly toxic at low concentrations.

Hydrogen sulphide

Hydrogen sulphide is a colourless gas with a distinctive odour of 'rotten eggs' at low concentrations, but can cause a loss of sense of smell at high concentrations (olfactory fatigue). The gas is produced by the decomposition of organic matter containing sulphur, and is commonly associated with sewage treatment works. The gas can also be generated in landfill sites by the degradation of gypsum, present in plasterboard, by sulphate-reducing bacteria in anaerobic conditions. Hydrogen sulphide may also occur dissolved within groundwater, derived from the alteration of iron pyrites present in both the Millstone Grit and Coal Measures. The gas is explosive in air in the range 4.4 to 45 volume %. The gas is highly toxic at low concentrations. Hydrogen sulphide is also highly toxic to vegetation.

Hydrogen

Hydrogen is a colourless, odourless and tasteless gas. It is non-toxic but can act as an asphyxiant. The gas is readily combustible, forming explosive mixtures with air in the range 4 to 74 volume % hydrogen.

Radon

Source of gas

Radon (Rn-222) is a naturally occurring radioactive gas which is derived from rocks, soils and groundwater containing uranium (U) and thorium (Th). Nationally, the main areas of relatively high levels of radon are associated with the following:

i) Areas underlain by rocks, or their weathering products, containing enhanced concentrations of uranium. The main rock types include certain granites, uraniferous mineral deposits, uraniferous black shales and phosphatic sedimentary rocks. In the Bradford District, levels of natural uranium are thought to be generally low, though local concentrations may be present in marine bands, other carbonaceous shales and coal seams present in the Millstone Grit and Coal Measures (Ball et al., 1992);

ii) Areas underlain by permeable rocks, superficial deposits and their weathering products. In the District, the principal geological units are sandstone and sand and gravel.

In a preliminary study, the NRPB collected data on radon levels throughout England. The study by Green *et al.* (1992) recorded 63 results for the Bradford postcode, with an average of 43 Bq m^{-3}. One result gave values in excess of the Government accepted Action Level of 200 Bq m^{-3}.

Nature of hazard

Alpha particles emitted from the decay of radon are the most important source of natural radiation for the UK public, with at least 50% of the average annual dose derived from this source (Clarke and Southwood, 1989). The National Radiological Protection Board (NRPB) has determined that prolonged exposure to high levels of radon radiation will increase the risk of lung cancer (O'Riordan et al., 1987).

Leachates

Source of leachate

Rain water or groundwater which percolates through waste becomes enriched in soluble components present as a primary component of the waste, or generated secondarily by chemical or biological reactions. The resulting solution may contain a highly variable mixture of inorganic, organic and microbial constituents. The quantity and composition of such leachates is dependent upon the volume, composition, age and density of the waste and site hydrology (Department of the Environment, 1986). The composition of typical leachates and component concentrations for landfills containing municipal wastes are shown in Table 21. Large volumes of leachate may be derived from sites with high contents of degradable, industrial and chemical wastes.

Historically in the UK, landfill operations practised a 'dilute and disperse' method of waste treatment. This entailed use of uncontained sites within which leachates were allowed to slowly discharge into surface waters and/or groundwaters, diluting the concentration of the leachate. This technique results in eventual refuse stabilisation, minimising the pollution potential of a site if disturbed in the future. However, this uncontrolled method may have serious detrimental effects on water quality (see Chapter 11) and as a consequence over recent years, licences for non-inert waste landfill operations have tended to stipulate storage of wastes in engineered containment sites with treatment of leachates.

Contamination of surface and groundwater may also result from water drainage from abandoned coal mines. The problems associated with mine drainage are discussed in Chapter 11.

Nature of Hazard

Leachates represent a risk of contamination if present in levels exceeding critical levels (Council Directives 80/68/EEC, 76/464/EEC; National Rivers Authority, 1992). The migration of this leachate into surface water courses and groundwater depends on a number of factors, including:

i) Presence of containment structures, such as impermeable linings and caps can inhibit leachate migration;

ii) Nature of drift deposits, and/or bedrock geology adjacent to the site. The migration of leachates may be enhanced where landfill sites are located on permeable strata, such as sandstone or sand and gravel, adjacent to faulted ground, or in areas of open workings;

Table 21 The composition and range of concentrations of the constituents of leachate from landfills containing municipal wastes (DoE, 1986; Oweis and Khera, 1990: concentrations in mg/l).

Component	Range domestic	Fresh wastes	Aged wastes
pH	3.5–8.5	6.2	7.5
Chemical Oxygen Demand (COD)	50–90000	23800	1160
Biochemical Oxygen Demand (BOD)	5–75000	11900	260
Total Organic Carbon (TOC)	50–45000	8000	465
Total coliform bacteria (cfu/100ml)	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	5–27700	5688	5
Manganese	0.6–41	27	2.1
Faecal coliform bacteria (cfu/1000ml)	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	3–15600	252	185
Potassium	35–2300	780	590
Calcium	0.1–36000	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

iii) Depth of the unsaturated zone. A particular problem arises from rising groundwaters. Landfill sites originally located in areas above the water table, may become saturated as water levels rise, either through cessation of pumping in mine workings, or through reduced abstraction for water consumption.

Migration of gases and leachates

Leachate plumes migrate in response to groundwater flow. The complex nature of groundwater flow and its implications for migration of contaminants is discussed further in Chapter 11.

Gases may migrate in response to a number of driving forces. These include falls in barometric pressure, which will increase gas flow toward the ground surface. Rising groundwater levels may pressurise the gas present in voids and also cause it to migrate towards the ground surface. Gases can also be dissolved under pressure in groundwater and may be released as the pressure drops, either as the water issues at the ground surface or within underground cavities. Gases may migrate toward the surface, either through permeable rocks, such as sandstone, along open joints or fractures, faults and bedding planes or through man-made disturbances, such as mine workings, tunnels, shafts or boreholes (Figure 26). Major faults, in particular, may be considered to be possible conduits for gas migration.

Gases which are released into the open air are readily dispersed and do not pose a problem. However, gases which accumulate in: a) poorly ventilated enclosed spaces, such as basements, foundations, caves, open mine workings and tunnels, or; b) beneath an impermeable capping of drift deposits, such as Till or Head, may become a hazard. If such a layer is penetrated during excavation, either for building foundations or for services such as pipelines, gases may migrate to the excavated surface. Waterlogging or freezing of the ground can result in the temporary formation of an impermeable capping, preventing migration of the gases to the surface. The resultant accumulation of gas at near surface levels may be released to the surface in hazardous concentrations when the ground has dried or defrosted.

Mine gases

In addition to the migration pathways described above, gases associated with disused coal workings may migrate toward the surface via open mine workings, roadways, adits and shafts, and areas of mine-related subsidence fractures. The latter results from subsidence, due to extraction of coal or related minerals, causing flexuring and widening of pre-existing fissures and joints. The effect is most noticeable in brittle sandstones, above and toward the margins of the areas of extraction (Williams and Aitkenhead, 1991). Although sandstone workings do not generate mine gases, it is possible that methane, carbon dioxide or oxygen-deficient air derived from disused coal workings may sometimes accumulate in the voids associated with sandstone workings.

Landfill gases

Landfill gases may migrate directly from the landfill site, or be dissolved in leachates emanating from such sites. In addition to the general migration pathways described above, where landfill sites are in former quarries or pits, blasting employed during the quarrying operation would probably enhance the network of joints present in the vicinity of the site (Williams and Aitkenhead, 1991).

Radon

Because of the short half-life of radon (3.825 days), transport mechanisms need to be rapid for the gas to reach the surface. Radon tends to migrate from source rocks by association with other gases, in particular methane and carbon dioxide. Radon may also be transported in solution, returning to a gas phase in areas of water turbulence, e.g. waterfalls, or pressure decrease, e.g. springs (Ball et al., 1991).

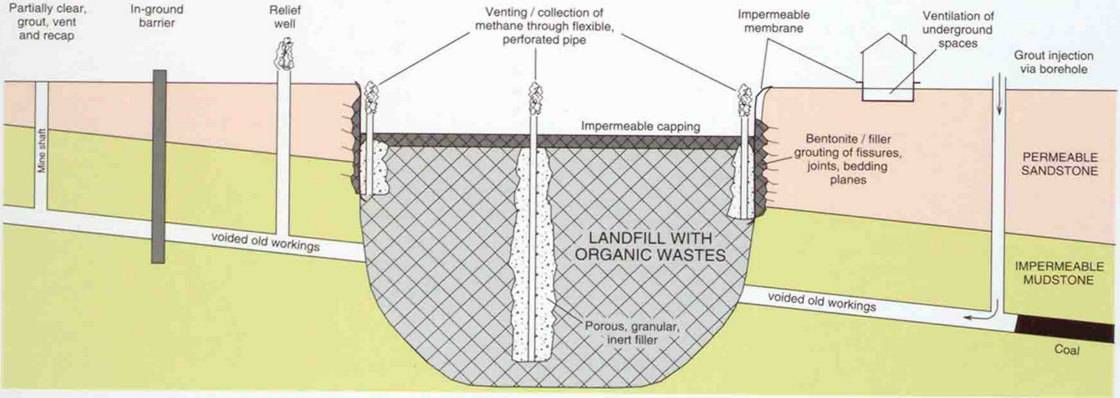


Figure 27 Remedial measures for the treatment of landfill sites and disused coal workings.

Radon may occur in higher concentrations in high permeability rocks present above a source rock. High radon levels are known to occur in Coal Measures sandstones elsewhere in the country (BGS, unpublished data). Major faults appear to act as conduits for the migration of radon. Impermeable drift deposits, such as till, may form a surface capping, reducing levels of radon reaching the groundsurface.

Concentrations in open air are normally very low and do not present a hazard. However, in poorly ventilated confined spaces the gas can accumulate and cause problems if individuals are exposed for long time periods.

Summary and recommendations

The hazards associated with the presence of methane and carbon dioxide are principally derived from landfill sites, but mine gas emissions may be locally significant in coalfield areas, including the south and east of the District. The presence of dissolved methane and hydrogen sulphide in groundwater, derived from the bedrock, may be potentially harmful. Toxic leachates from landfill sites, are an issue in many urban areas in the UK, including, within the District the area to the south of Airedale. The presence of these problems, and the effect that any development would have on their migration, should be considered during any site investigation. In addition, the possible presence of carbon monoxide, sulphur dioxide, hydrogen and radon should be considered as a potential hazard in the District.

It is recommended that prior to any site development in areas prone to problems with hazardous gases or leachates, site investigations should be used to ascertain the levels of both gases and leachates. **Where problems with gases and/or leachates are identified, it is important that expert advice should be sought to identify the scale, volume, emission rates and risks.** Identification of the source and likely pathways for gases and leachates will permit the determination of the probable geographical extent of the problem, the likely flow rates and the most appropriate remedial measures. Treatment of sites prior to development is generally less expensive than resolving a problem after development is complete.

Guidance on the detection and measurement of gases and identification of the source and recommendations on the nature of site investigations are provided in the CIRIA report (Crowhurst and Manchester, 1992) and reviewed by Appleton (1995). Information on site investigation and monitoring is also covered in Waste Management Paper No. 27 (Department of the Environment, 1989).

The Building Regulations Approved Document C (HMSO, 1992) indicates that if methane levels in the ground of 0.05 volume % or carbon dioxide of 0.5 volume % are exceeded, protective measures may be required. If methane concentrations in the ground are unlikely to exceed 1 volume %, or carbon dioxide concentrations exceed 1.5 volume %, houses and small buildings are recommended to be constructed with a low-permeability gas barrier over a high permeability layer from which gas can be extracted. The sub-floor design is a requirement where carbon dioxide concentrations exceed 5 volume %. For methane concentrations in excess of 1 volume %, specific guidance should be sought.

The following recommendations relate to preventive or remedial measures for the treatment of areas where mine gas, landfill gas, radon and leachates may represent a problem to existing or future developments.

Mine Gas

Remedial measures for the treatment of disused coal workings are summarised in Figure 27 and discussed below.

a) Treatment of mine workings

i) The problem of build-up of mine gases in old, disused mines can be treated by the sinking of relief wells to allow the controlled ventilation of the open voids (Figure 27). It is possible that the gas could be exploited as a resource. Research is underway to determine the economic viability of Coal Bed Methane (Weighell, 1992), though it is unlikely that the exposed coalfield of West Yorkshire will represent a suitable prospect.

ii) Old workings may be infilled and grouted to act as a barrier to gas migration, although care is needed that the emissions are not simply deflected to another location.

iii) Where migration of gases to the surface is via a shaft, the recommended treatment is to expose and partially

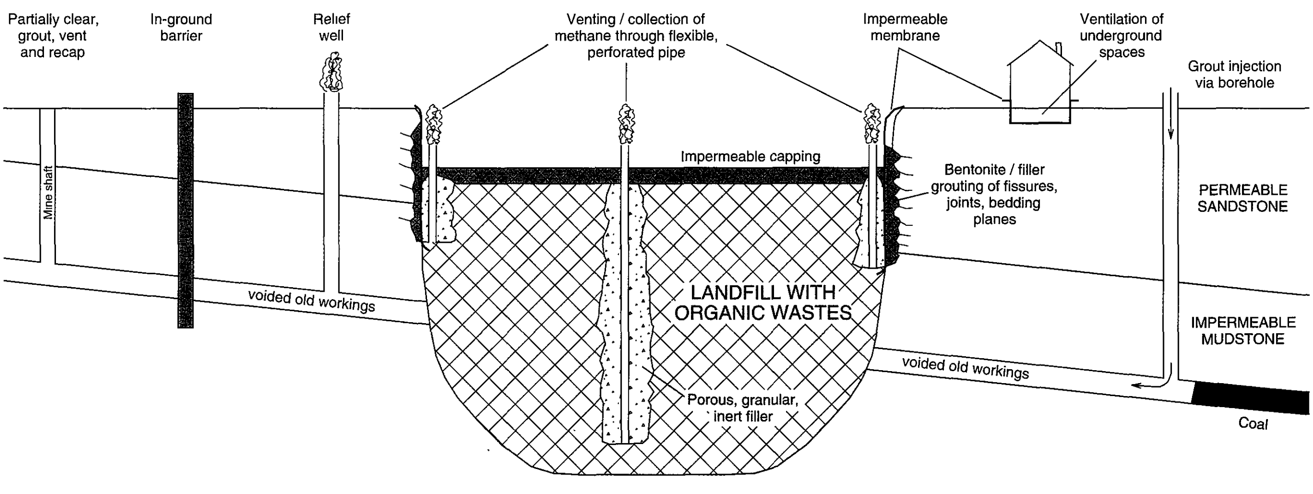


Figure 27 Remedial measures for the treatment of landfill sites and disused coal workings.

clear the shaft, backfill with coarse gravel and install venting pipes and recap the shaft with concrete (Hooker and Bannon, 1993).

b) Treatment of building

i) Installation of a barrier or sealing of voids to prevent ingress of gases into a building

ii) Underground spaces in buildings at risk from mine gas should be ventilated to avoid build-up of the gas. Monitoring should be maintained to ensure that ventilation is working.

c) Treatment of underground works

i) Water borehole headworks, and borehole itself, should have free ventilation to ensure there is no gas build up

ii) Tunnel linings should be made as water-tight as practicable. For water tunnel schemes, the system contents should be regularly flushed.

Landfill Gas

During the planning procedure it is important that the possible effects of locating landfill sites near to existing dwellings and other sites potentially at risk from gas emissions or leachates are taken into consideration. The licensing of new landfill sites and the monitoring of established sites is the responsibility of the Waste Regulation Authority, whereas closed sites are monitored by Environmental Health. Before landfill sites are developed, it is important to carry out a thorough site investigation, to determine the suitability of geological or hydrogeological conditions. In particular, the site investigation should consider the permeability of the containing medium, either bedrock or superficial deposit, presence of faults, and the possible presence of disused workings, mine entries, tunnels. For proposed landfill sites containing biodegradable waste, Williams and Aitkenhead (1991) have proposed the following recommendations for a site survey:

i) Carry out a detailed topographical survey;

ii) Carry out a geological survey with the production of a detailed geological map, cross-sections and graphical logs. This requires the consultation of existing archival information, such as geological maps and mine plans, in addition to data derived from the logging of surface sections, boreholes and trial pits and from geophysical surveys;

iii) Site reports should include photographs of the geology and the general site conditions, with particular attention to water seepage and fracturing.

Where it is intended to develop an area in the vicinity of a completed landfill site, similar appraisals can be employed to assess the potential for gas migration and zones of potential risk. In such circumstances, sites should be investigated by drilling with measurement of gas composition, the temperature gradients with depth, the direction and rate of groundwater flow and the permeability of subsurface materials (Williams and Aitkenhead, 1991). The vulnerability of structures built near to existing landfills depends on a number of factors, identified by Myers et al. (1994), each of which should be assessed:

a) The nature and age of the waste, in particular the amount of biodegradable material, the moisture content and the degree of compaction;
b) The nature of containment, if any. Surface capping alone could result in lateral migration of gases, whereas full containment may concentrate gases to hazardous levels;
c) The nature of remedial measures, if any, such as culverting or stream diversion, constructing drainage ditches or embankments to contain refuse, screening wastes (Williams, 1980);
d) The presence of a driving force, such as rising groundwater;
e) The geological setting, in particular the permeability of lithologies and the presence of joints, fractures or faults;
f) The hydrogeological setting, in particular the groundwater level and flow direction;
g) The presence of man-made structures, such as sewers, utility cables and pipelines and old mine workings;
h) The nature of the structures, which may be designed to minimise the risk from landfill gases;
i) The distance to the structures.

Potential remedial measures for the treatment of landfill sites are summarised in Figure 27 and discussed below.

i) Migration of landfill gases may be limited by lining of the site with an impervious membrane and introduction of courses of inert, permeable, granular fill and vent stacks (Plate 5) to prevent excessive build-up methane from the waste material. For large landfill sites it may be economically viable to exploit the gas as a source of fuel.

ii) Retrospective sealing of old landfill sites may be carried out by grouting fissures present in the adjacent bedrock with bentonite/filler grout.

iii) In extreme circumstances, the waste can be excavated and the site lined with a compacted cohesive sealant of low permeability or by low permeability membrane.

iv) Sites of known high levels of methane generation should be carefully monitored and levels controlled by collection or flaring.

v) Underground spaces in buildings at risk from landfill gas should be ventilated to avoid build-up of the gas and monitoring employed to ensure that remedial measures are successful.

vi) Assessment of the entry points of gas into buildings should be undertaken and potential entry points could be sealed by impermeable membranes.

Guidelines for the control and treatment of landfill gases are provided in Department of the Environment circulars 21/87 (DoE, 1987) and 17/89, ICRCL Guidance Note 17/78 and Waste Management Paper 27 (DoE, 1989).

Radon

A rudimentary programme of radon potential mapping has been undertaken for the District to provide a broad guide to the level of radon emissions from the ground (Green et al., 1992). Radon does not appear to be a significant problem in the District, though one dwelling from a study of 63 had radon levels above the recognised action level. Where radon levels are found to be high, it is recommended that more detailed studies and monitoring of specific dwellings should be undertaken to identify the source and possible migration pathways of the gas. As major faults are likely to be zones of migration of radon, it is important that site investigations are designed to locate the precise position of faults which are shown on geological maps. Remedial measures include improved ventilation of enclosed spaces, in particular cellars.

For further information on the problem of radon in dwellings, the 'Householder's Guide to Radon' has been issued by DoE. For concerns regarding radon gas in mines and civil engineering operations, the regulations and abatement measures are presented in the 'Approval Code of Practice Part 3: Exposure to Radon. Ionising Radiation Regulations, 1985 (Health and Safety Executive).

Leachates

Planning Policy Guidance 23 (Department of the Environment, 1994) states that "the planning authority should consider and set out in the waste local plan the appropriate criteria for the location of each method of treatment or disposal needed for their area and make adequate provision for suitable sites". It is important that the possible effects of locating landfill sites in the vicinity of vulnerable targets, such as surface water courses, springs, lakes and in particular in catchment areas for surface and groundwater abstraction sites (see Chapter 11), are taken into consideration during the planning procedure. Migration of leachates may be limited by ensuring, through a thorough site investigation, that landfill sites are located in areas with suitable geological or hydrogeological conditions, or that measures such as lining of the site with an impermeable membrane are carried out. The site investigation should consider the permeability of the containing medium, either bedrock or superficial deposit, the presence of faults, the source of any site water and the possible presence of disused workings, mine entries, tunnels.

For active and former landfill sites it may be necessary for large sites containing domestic, industrial or chemical wastes to monitor groundwater quality, water levels and regional hydraulic gradients adjacent to the landfill site. The National Rivers Authority (NRA) has the responsibility to monitor and protect surface waters and groundwaters, under the Water Resources Act 1991. The NRA has adopted a policy and practice for groundwater protection (National Rivers Authority, 1992). It has become apparent that the migration of leachates in the saturated zone may be highly complex and in order to identify site hydrogeology and plume development a large number of monitoring boreholes may be required (Williams, 1980).

Where problems arise in former sites, it may be necessary to introduce an impermeable surface clay capping, to limit the influx of surface water into the fill material, thus reducing degradation rates and the degree of leachate development. However, such a capping may prevent the vertical escape of landfill gases, resulting in its lateral migration. Impermeable linings to landfill sites will prevent lateral gas migration and have the added benefit of limiting the interaction of groundwater with waste materials. However, for former landfill sites this would require the excavation of the landfill. In such circumstances, it may be of no greater expense to remove the waste material completely from the site. This, however, may require the infill of the excavated void with inert fill to maintain the stability of quarry walls (Williams and Aitkenhead, 1991).

13 Summary

1. The maps and databases contained within this report provide only a summary of the information held by the British Geological Survey, who should be consulted if more detailed maps or additional data are required.

2. Where the nature of the bedrock or superficial deposits are of significance to a development, it is important that a site investigation is carried out to assess the geology. Where artificial deposits may be present, and pose a potential hazard through ground instability and/or contamination, it is recommended that during the initial phase of a site investigation the archival search should include a determination of former land-use.

3. The District contains numerous geological exposures, particularly within active or disused quarries, which represent an important educational resource. It is important that the possible significance of geological sites are taken into consideration prior to any development of a site.

4. Sandstone is the main mineral resource in the District, with eleven quarries currently operating and demand for local stone likely to continue in the near future. The main factors hindering further extraction are sterilisation of the resource by urban development and conflicts with other forms of land-use. As existing quarries become exhausted and in order to meet any future demand for stone products, it will be necessary for either new quarry sites to be found, or old sites reopened. There will be a continuing small demand for the use of fireclay in the manufacture of glasshouse pots. There is a potential for future small-scale opencasting of coal and extraction of sand and gravel in the District. During any future redevelopment of urban areas, minerals currently sterilised by surface development may become available for extraction. As a future mineral resource, sandstone, fireclay, coal and sand and gravel need to be considered for possible protection.

5. The District has had a long history of underground mining for coal, fireclay, ironstone and sandstone. Despite the absence of active mining for these minerals, the presence of old abandoned workings at shallow depths and mine entries represents a potential hazard to development in parts of the District. It is essential that in an area of known, or possible underground mining, that a detailed and thorough site investigation is carried out by suitably qualified professionals. The aims of such a site investigation should be to identify the hazard, to gather information which will assist in the siting of structures, to aid the design of ground improvement works and the design of foundations. The site investigation should include a comprehensive search through archival material, field reconnaissance and proving techniques.

6. 201 landslips were recorded in the District, the majority of which occur on the steep north-facing slopes of the Aire and Wharfe valleys and their tributaries. Many are ancient features which are now dormant and have become degraded and vegetated or superficially remodelled by later events. Under present conditions these landslips may remain dormant unless the factors controlling their stability are adversely disturbed by natural processes or human interference. The occurrence and distribution of existing landslips provides an indication of those areas where slopes previously unaffected by landslipping may pose stability problems in the future. The presence of unstable, or potentially unstable, slopes does not preclude development at a site, provided the problem is recognised, properly evaluated and effectively remedied and maintained. The most effective strategy for dealing with unstable, or potentially unstable, ground is the recognition of problem areas in advance of development so that avoidance or pre-emptive works can be carried out. For proposed development sites in areas of known or possible unstable ground, assessment of stability conditions of the site and its environs should be ascertained from a desk study of available information, inspection of aerial photography, 'walkover' surveys and engineering geomorphological mapping, followed by site investigations to establish the factors controlling stability. Because ground and groundwater conditions can vary unpredictably over relatively short distances, reliable stability assessments may only be determined from data obtained at individual sites and should not be extrapolated to apparently similar sites nearby. If development on ground proved to be unstable by site investigation cannot be avoided, it must be made stable by appropriate engineered remedial works prior to development. Such work is a specialist task and should be carried out under the supervision of a competent engineer.

7. Engineering ground conditions vary markedly across the District but should pose no major problems to construction and development, provided that adequate information is obtained to properly confirm the material, geotechnical and groundwater characteristics at specific sites. This should involve a thorough review of existing information (e.g. borehole records and SI reports) followed by competent and properly focused site investigations at the feasibility and design stages of planned development projects. General problems which may be encountered, are most likely to be associated with the presence of landslips or potentially unstable ground on steep valley side slopes, deep and variable bedrock weathering profiles related to geological faults, variability in thickness and material characteristics of the natural superficial deposits, and the likelihood of extreme variability in the material composition and compaction characteristics of man-made deposits such as waste tips and infilled ground (some of which may contain materials hazardous to health and the environment). In the eastern and southern parts of the District a major factor governing the engineering ground conditions is the presence of underground voids at shallow depth associated with past mineworking for both coal

and sandstone. In these areas, consideration must be given to the potential development of 'crown holes' at ground surface due to collapse of the old workings and/or the penetration of foundations into near-surface voids. Provided the ground conditions have been properly established and potential problem areas evaluated, virtually all could be overcome by modern engineering methods, at varying cost.

8. Public water supply to the District is wholly dependent on surface water sources, mainly from reservoirs present both within and outside the District, and from licensed spring sources. These supplies have generally been able to meet demand, though during exceptional drought years there have been threats of supply restrictions. Groundwater abstraction for industrial purposes is of importance, though total useage has declined over recent decades. The main aquifers exploited in the District are the sandstones of the Millstone Grit and Lower Coal Measures. The complex pattern of faults present in the District are considered to have a great significance to current and potential supply of groundwater. Little information is available on the nature of groundwater levels in the District, though evidence from other urban areas in the UK suggests that levels are rising.

   A substantial improvement in water quality has been facilitated by construction of new storm sewers and combined sewer overflow systems and the promotion of more regulated discharges of trade effluents. The main factors which may potentially influence surface water quality in the District include combined sewage outflows and sewage treatment works, effluents from textile mills and other industrial pollution, contamination from former gasworks sites, leachates from old landfill operations and discharges of acid, ferruginous water from abandoned colliery mine workings. Groundwater quality in the District is at risk from harmful leachates from old landfill sites and acid mine drainage from disused colliery workings. The presence of Non-Aqueous Phase Liquids which include petroleum and diesel fuels and halogenated solvents are a particular concern.

   The risk of flooding, which has long been a problem in the District, has been reduced by the construction of flood defence systems, used in conjunction with a policy of protection of washland areas from development.

9. The hazards associated with the presence of methane and carbon dioxide is principally derived from landfill sites, but mine gas emissions may be locally significant in the south and east of the District. Toxic leachates from landfill sites, are an issue in the District, particularly to the south of Airedale. In addition, the possible presence of carbon monoxide, sulphur dioxide, hydrogen and radon should be considered as a potential hazard in the District. Radon does not appear to be a significant problem in the District, though where radon levels are found to be high, it is recommended that more detailed studies and monitoring of specific dwellings should be undertaken to identify the source and possible migration pathways of the gas. In areas prone to problems with hazardous gases or leachates, site investigations should be used to ascertain the levels of both gases and leachates. Also, prior to the development of a new landfill site it is important to carry out a thorough site investigation to determine the suitability of geological or hydrogeological conditions.

14 Technical appendices

14.1 Data Sources

The main sources of archival information for the study area, used during the project, summarised in Table 1 are:

British Geological Survey

- published geological maps at 1:10 000-, 1:10 560- and 1:50 000-scale. An index of geological maps held by BGS for the area is provided in the technical appendices (Appendix 14.4);
- geological field slips at 1:10 000-, 1:10 560-scale. As modern field slips may present confidential data, they are not widely available for consultation;
- geological notebooks, with entries for archival note-books indexed for each 1:10 000 geological map area, whereas notes from the recent geological resurvey are held in card form, with each locality having a unique registration number and the index data held digitally;
- landslip data collected for 201 sites visited in the field;
- borehole and trial pit records; at the commencement of the project, 1451 registered borehole and trial pit records were held in the the BGS database. As a result of the collection of site investigation data during the study, this number has increased to 10 823. The distribution of borehole data in the study area, at commencement and completion of the project, is shown on Figure 28;
- aerial photographs; a part coverage (about 80% of the district) at 1:25 000-scale, flown in 1993, was purchased from Geonex UK;
- hydrogeological data, including well records providing information on historic water levels and water chemistry and the BGS Aquifer Properties Manual, with information about the permeability and porosity of the principal aquifers in the UK;
- library holdings, including serials and books;
- geophysical data, including aeromagnetic and gravity data and seismic sections;
- abandonment mine plan data, in particular plans and associated information for abandoned sandstone workings.

City of Bradford Metropolitan Council (CBMC)

- site investigation reports, particularly for the main drainage and road schemes and for public developments;
- aerial photographs; a complete colour, stereoscopic coverage at 1: 3000-scale (urban areas) and 1:6000-scale (rural areas), flown in 1988-89, was made available to BGS;
- landfill data, comprising a listing and site maps at 1:10 000-scale of 361 landfill sites with notes on available information for each site;
- Unitary Development Plan; a deposit draft version of the plan including proposal maps, the policy framework and details of the local proposals, including information of Sites of Special Scientific Interest and Sites of Ecological and Geological Interest;
- town plans for the City of Bradford Borough and West Riding County Council, from the 1950s and 1960s, with information on land-use.
- Cliffe Castle Museum provided information on extractive mineral industries, local references and possible Regionally Important Geological/ Geomorphological Sites;

Highways, Engineering & Technical Services Joint Services Committee

- large volume of site investigation data and soil reports;
- files pertaining to mining investigations, in particular, the location of mine entries.

Ordnance Survey

- modern and historical topographic maps, including four sets of maps, consulted for shaft and quarry locations, landuse data, drainage, etc.. The maps include a primary County Series from the 1840–50s and revision survey from the 1900–30s, both at 1:10 560-scale, a resurvey published at 1:15 560-scale on the National Grid in the 1950s, and a modern survey at 1:10 000-scale, published in the 1970–90s. An index of OS maps for the area is provided in the appendix 14.4;
- Digital Terrain Model (DTM) data used to produce the slope steepness map.

British Coal (data now held by the Coal Authority)

- interpolated outline of mine plans, with fifteen seam plots at a scale of 1:25 000, comprising working outlines for individual seams and interpolated in-seam depth information;
- interpolated mine entry positions, comprising a single plot at a scale of 1:25 000;
- list of coal abandonment plans held by the coal authority;
- opencast sites; data concerning sites which have been prospected but not worked were already held at the BGS.

Mineral Valuers Office

- annotated BGS geological maps indicating errors discovered by the Mineral Valuer;
- abandonment mine plans, in particular, fireclay and sandstone workings.

National Rivers Authority

- the NRA licensing database, reproduced in appendix 14.3;
- the NRA provided a MSc. dissertation on groundwater in Bradford, with information on licensed abstractions, groundwater quality, drawdown effects of abstraction and transmissivity data;
- Catchment Management Plans with surface water quality maps, details of Aquifer Protection Policy and extent of Washlands;

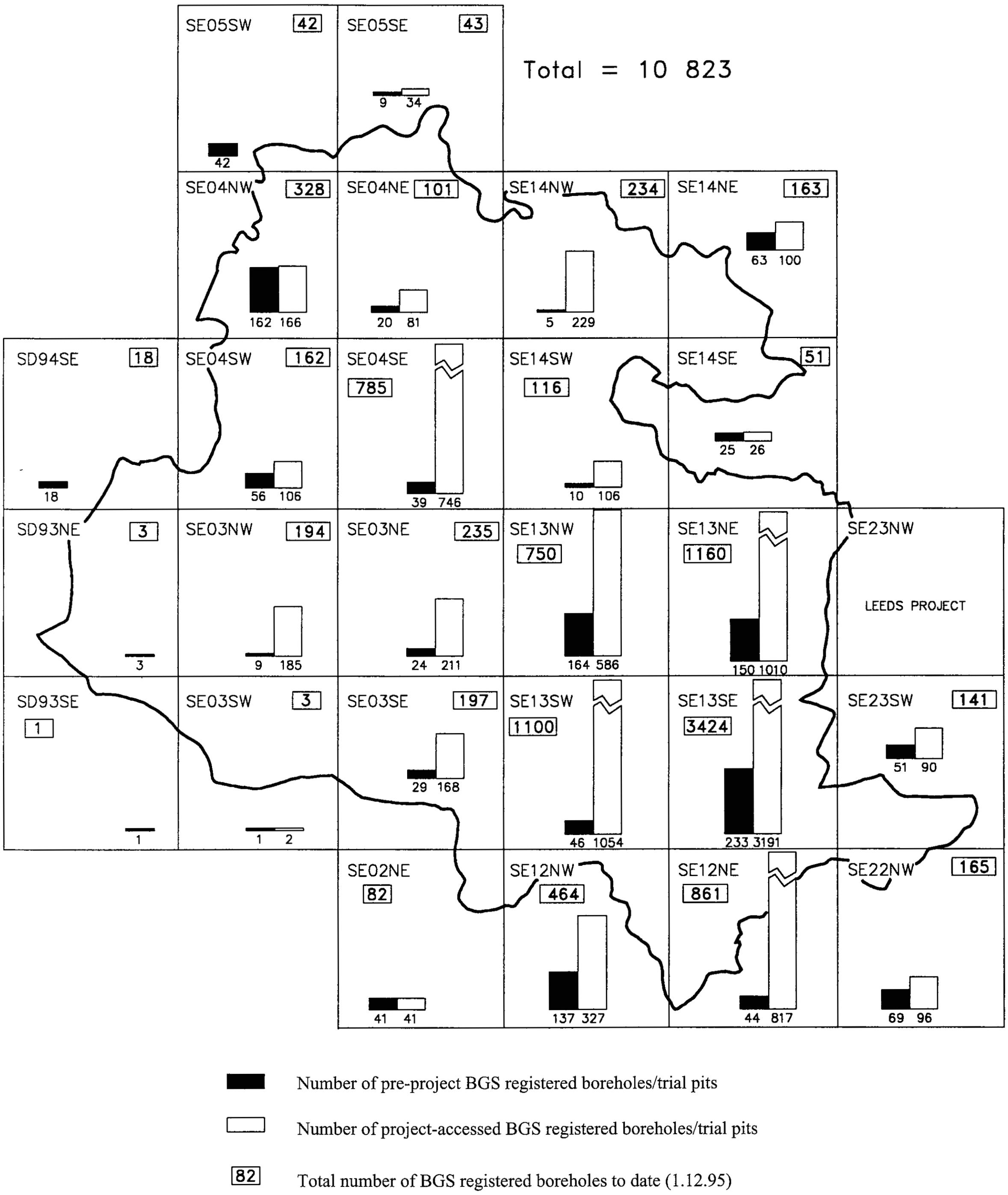


Figure 28 Histograms showing the number of boreholes/trial pits for each 1:10 000 sheet by 1.12.95.

- information on mine drainage;

West Yorkshire Waste Regulatory Authority

- list and summary information of 69 licensed landfill/ waste storage/ waste treatment sites.

Civil Engineering Consultants

- several civil engineering consultants, active in the Bradford area, allowed the project to use information from site investigation reports which they hold. A comprehensive listing of the consultants is provided below;
- Fennell, Green & Bates provided numerous fireclay and coal abandonment mine plans.

Department of Environment

- lanslide data held on the 'UK Landslide Inventory Report';
- numerous Planning Policy Guidance Notes, Mineral Planning Guidance Notes, relevant DoE circulars and the 'Contaminated Land Research Report No.3'.

The contact addresses and telephone numbers of the contractors and Department of the Environment, are:

CONTRACTORS

British Geological Survey
Kingsley Dunham Centre
Keyworth
Nottingham
NG12 5GG
Tel: 0115 936 3100

Entec UK Ltd
Camden House
St. Johns
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Dr C Snee
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CLIENT

Department of the Environment,
Minerals and Waste Planning Division
2 Marsham Street
London
SW1P 3ED
Tel: 0171 276 3961

Contact addresses and telephone numbers of organisations providing data or advice for the study:

CONSERVATION AND EDUCATION ISSUES

English Nature
Earth Science Branch
Northminster House
Peterborough
PE1 1UA
Tel: 01733 340345

City of Bradford Metropolitan Council
Geological Curator
Cliffe Castle
Spring Gardens Lane
Keighley
West Yorkshire
BD20 6LH
Tel: 01535 618238

Senior Keeper
Industrial Museum
Moorside Mills
Moorside Road
Bradford
BD2 3HP
Tel: 01274 631756

West Yorkshire Archaeology Service
14 St.John's North
Wakefield
West Yorkshire
WF1 3QA
Tel: 01924 296797

West Yorkshire Archive Service, Bradford
15 Canal Road
Bradford
BD1 4AT
Tel: 01274 731931

Principal Archivist
West Yorkshire Archive Service, HQ and Wakefield
Registry of Deeds
Newstead Road
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WF1 2DE
Tel: 01924 295982

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City of Bradford Metropolitan Council
Transport and Planning Division
Jacobs Well
Manchester Road
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BD1 5RW
Tel: 01274 754605

Mineral Valuer
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42 Eastgate
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LS2 7LE
Tel: 0113 242 3388

Minerals Unit
British Geological Survey
Kingsley Dunham Centre
Keyworth
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NG12 5GG
Tel: 0115 936 3100

MINED GROUND

The Coal Authority
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Ashby Road
Stanhope Bretby
Burton on Trent
Staffordshire
DE15 0QD
Tel: 01283 553462

Mineral Valuer
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42 Eastgate
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LS2 7LE
Tel: 0113 242 3388

National Data Records Centre
British Geological Survey
Kingsley Dunham Centre
Keyworth
Nottingham
NG12 5GG
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Fennell, Green and Bates
Mining Engineers, Surveyors and Valuers
25 Smyth Street
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WF1 1ED
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ENGINEERING GROUND CONDITIONS AND SITE INVESTIGATION DATA

City of Bradford Metropolitan Council
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BD1 5BY
Tel: 01274 391082

West Yorkshire Highways and Technical Services
Joint Services Committee
Harbury Road
Ossett
West Yorkshire
WF5 0BZ
Tel: 01924 260621

The Department of Transport
Yorkshire and Humberside Construction Programme Division
Jefferson House
27 Park Place
Leeds
LS1 2SZ
Tel: 0113 254 1249

British Rail, Eastern Track Renewal
Old Biscuit Warehouse
Leeman Road
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YO2 4XD
Tel: 01904 522298

British Waterways Board
Technical Services
Wellington Park House
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Amec Civil Engineering Limited
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Tel: 01257 480264

Babtie Shaw and Morton
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Bradshaw Buckton and Tonge
Consulting Engineers
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31 Waterloo Lane
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Bullen and Partners
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Eastwood and Partners
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23 Kingfield Road
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Exploration Associates
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Geotechnical Engineering (Northern) Limited
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Michael D Joyce Associates
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National Grid Company plc
Civil Engineering Centre
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Burymead House
Portsmouth Road
Guildford
Surrey
GU2 5BN
Tel: 01483 69951

National House Building Council
Buildmark House
George Cayley Drive
Clifton
York
YO3 8XE
Tel: 01904 691666

Norwest Holst Soil Engineering Limited
Parkside Lane
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LS11 5SX
Tel: 0113 271 1111

Robinson Consulting Engineers
Grantham House
Laisteridge Lane
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BD7 1QT
Tel: 01274 729441

Soil Mechanics
Glossop House
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Finchamstead
Wokingham
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RG11 4QW
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Sub Soil Surveys Limited
Chaddock Lane
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M29 7LD
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British Geological Survey
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OX10 8BB
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LANDFILL DATA

West Yorkshire Waste Regulation Authority
69 Bradford Road
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HD6 1RS
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City of Bradford Metropolitan Council
Transport and Planning Division
Jacobs Well
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Thematic Maps and Onshore Survey Division
British Geological Survey
Kingsley Dunham Centre
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NG12 5GG
Tel: 0115 936 3100

TOPOGRAPHIC MAPS AND DIGITAL MAP DATA

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AERIAL PHOTOGRAPHY

Geonex UK Limited
92-94 Church Road
Mitcham
Surrey
CR4 3TD
Tel: 0181 640 1971

City of Bradford Metropolitan Council
Transport and Planning Division
Jacobs Well
Manchester Road
Bradford
BD1 5RW
Tel: 01274 754605

14.2 Mineral workings in the Bradford District

Sandstone
Branshaw Quarry, Holme Lane, Oakworth
SE 034 402
Millstone Grit, Woodhouse Grit Flags
Ashlar Stone Products
Manywells Industrial Estate
Cullingworth
Bradford BD13 5DX
Tel: 01535 275087

Nab Hill Delph, Coldedge Road, Oxenhope
SE 035 324
Millstone Grit, Rough Rock Flags
H Reddihough
Allendale
Hebden Road
Haworth
Keighley BD22 8RQ
Tel: 01535 643983

Naylor Hill Quarry, Cullingworth Moor
SE 040 365
Millstone Grit, Woodhouse Grit
Dennis Gillson & Son (Haworth) Ltd.
Black Moor Road
Haworth BD22 9SU
Tel: 01535 643317

Hainworth Shaw Quarry, Cradle Edge, Harden Moor
SE 066 388
Millstone Grit, Rough Rock Flags
A Bailey
Shaw Lane
Keighley BD21 5QR
Tel: 01535 604340

Midgeham Cliff End Quarry, Harden Moor
SE 072 382
Rough Rock Flags
Yorkshire Quarries Ltd.
Realtex House
2 Leeds Road, Rawdon
Leeds LS19 6AX
Tel: 0113 250 5111

Buck Park, Whalley Lane, Cullingworth
SE 071 352
Millstone Grit, Rough Rock
Cutting Edge (Aggregate Supplies) Ltd.
c/o Station Road
Hipperholme
Halifax HX3 8HW
Tel: 01422 202695

Bank Top Quarry, Wilsden
SE 091 375
Millstone Grit, Rough Rock
Whitehall Stone Sales
Lee Lane
Cottingley
Bradford BD16 1UA
Tel: 01535 272273

Tenyards Quarry, Denholme
SE 080 340
Lower Coal Measures, Elland Flags
R E Atkinson
42 Garden Road
Brighouse, Halifax

Chellow Grange Quarry, Chellow Heights
SE 121 353
Lower Coal Measures, Elland Flags
H Parker & Son
Haworth Road
Bradford BD9 6NL
Tel: 01274 542439

Deep Lane Quarry, Crossley Hall
SE 130 327
Lower Coal Measures, Elland Flags
Yorkshire Stone Quarries (Bradford) Ltd
c/o Fagley Lane
Off Harrogate Road
Eccleshill
Bradford BD2 3NT
Tel: 01274 637307

Bolton Woods Quarry, Bolton Woods
SE 163 362
Lower Coal Measures, Elland Flags
Berry & Marshall (Bolton Woods) Ltd.
c/o Fagley Lane
Off Harrogate Road
Eccleshill
Bradford BD2 3NT
Tel: 01274 637307

Apperley (Rawdon) Quarry, Harrogate Road, Apperley Bridge
SE 196 390
Millstone Grit, Rough Rock Flags
Russell Stone Merchants
Westside Mills
Ripley Lane
Bradford BD4 7EX
Tel: 01274 727200

Fireclay
Dog and Gun Quarry, Oxenhope
SE 093 343
Lower Coal Measures, Halifax Hard Bed
Parkinson-Spencer Refractories Ltd
c/o Holmfield
Halifax HX3 6SX
Tel: 01422 244472

14.3 Index of licensed surface, spring and groundwater sources

Presented as two tables, for spring & groundwater and surface water abstraction sites, summarised from National Rivers Authority data.

The licence number shown on the tables are those presented on Map 8.

General Use includes Domestic (Dom), Agricultural (Agr), Irrigation (Irrig), General Industrial (Gen Ind).
Licence per hour (Lic. Hour) is recorded in metres^3/hour.
Licence per day (Lic. Day) is recorded in thousand cubic metres per day (tcmd).
Licence per year (Lic. Year) is recorded in thousand cubic metres per annum (TCMA).

For further information on licensed water abstraction data, the National Rivers Authority should be contacted.

14.4 List of Topographical and Geological Maps and Technical Reports

Availability of maps and technical reports, as of January 1996.

Topographical Map	Publication Date	Geological Map	Geologist	Publication Date	Technical Report
1:10 000-scale					
SE02NE	1989	Halifax	M Stewart	1994 (Provisional)	
SE03NW	1985	Haworth	N Aitkenhead	1995 (Provisional)	
SE03NE	1982	Cullingworth	J G Rees	1994	WA/94/74
SE03SW	1972	Oxenhope	C N Waters	1995 (Provisional)	
SE03SE	1990	Denholme	C N Waters	1994 (Provisional)	
SE04NW	1993	Silsden	R Addison	1995 (Provisional)	
SE04NE	1992	Addingham	N Aitkenhead	1995	
SE04SW	1993	Steeton	R G Crofts	1994	WA/94/79
SE04SE	1992	Keighley	R G Crofts	1995	WA/94/80
SE05SW	1992	Embsay & Draughton	N Aitkenhead	1995 (Provisional)	
SE05SE	1992	Beamsley	N Aitkenhead	1995 (Provisional)	
SE12NW	1986	Shelf	M Stewart	1994 (Provisional)	
SE12NE	1991	Low Moor	R Addison	1995 (Provisional)	
SE13NW	1982	Bingley	J G Rees	1994	WA/94/75
SE13NE	1987	Shipley	N S Jones	1995	
SE13SW	1988	Clayton	C N Waters	1995	WA/95/32
SE13SE	1993	City of Bradford	C N Waters	1995	WA/95/39
SE14NW	1993	Ilkley	M Stewart	1994 (Provisional)	
SE14NE	1973	Burley-in-Wharfedale	M Stewart	1994 (Provisional)	
SE14SW	1992	Bingley Moor	N Aitkenhead	1995	WA/95/41
SE14SE	1973	Guiseley	N Aitkenhead	1995 (Provisional)	
SE22NW	1986	Birstall	R Addison	1995 (Provisional)	
SE23NW	1978	Horsforth	D G Tragheim	1991	WA/91/40
SE23SW	1984	Pudsey	R Addison	1995 (Provisional)	
SD93NE	1979	Crow Hill	C N Waters	1995 (Provisional)	
SD93SE	1979	Wadsworth	C N Waters	1995 (Provisional)	
1:10 560-scale					
SD94SE	1956	Sutton-in-Craven	R G Crofts	1994 (Provisional)	

Provisional maps are those for which only a part 1:10 000-scale map is available at the date of publication.

Table 22 NRA Groundwater and Spring Water Abstraction Data

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SD93 NE								
SD 9740 3810	3861	Spring	Dom & Agr.	0	0	2.273	EXECUTORS OF H BANNISTER	C/O DAVIS & BORING, 6/8 MAIN STREET, KIRBY LONSDALE
SD 9940 3790	3864	Groundwater	Dom & Agr.	0	0.003	0.909	MR W BOULBY	DAISY MOUNT, OAKWORTH, KEIGHLEY.
SD 9980 3730	313601	Groundwater	General Industrial	0	0.005	1.137	PONDEN MILL LTD	CRAVENDALE HOUSE, HARGREAVES STREET, CROSS HILLS, KEIGHLEY
SD94 SE								
SD 9880 4170	177902	Spring	Dom & Agr.	0	0.005	1.659	ROBERT SMITH	HILL TOP FARM, SUTTON-IN-CRAVEN, NR KEIGHLEY
SE03 SE								
SE 0700 3230	4737	Groundwater	General Industrial	50	0.625	160	DENHOLME VELVETS LTD	FORESIDE MILLS, DENHOLME CLOUGH, DENHOLME, BRADFORD
SE 0880 3098	48503	Groundwater	Dom & Agr.	0	0.005	1.137	MR TONY BARRETT	SHUGDEN HEAD FARM, ROPER LANE, AMBLERTHORNE, QUEENSBURY, BRADFORD
SE 0900 3030	688	Groundwater	General Industrial	18.184	0.364	90.92	JOHN FOSTER & SONS LTD	BLACK DYKE MILLS, QUEENSBURY, BRADFORD
SE 0900 3040	5636	Groundwater	Dom/Agr./Irrig	0.23	0.002	0.028	UNION CROFT CRICKET CLUB	C/O MR N MYERS, FORGE COTTAGE, 1–3 FORD HILL, QUEENSBURY, BRADFORD
SE03 NE								
SE 0820 3540	5509	Groundwater	Dom & Agr.	20.45	0.256	61.36	MALCOLM BARKER	THE HAVEN, STATION ROAD, WILSDEN, BRADFORD
SE 0510 3670	3800	Groundwater	Domestic Use Only	1.75	0.002	0.546	BASS LTD	HIGH STREET, BURTON ON TRENT
SE 0540 3650	5038	Groundwater	Dom & Agr.	0	0.009	3.319	J BROOKSBANK	BROWN HILL FARM, CULLINGWORTH, WEST YORKSHIRE
SE 0547 3749	5878	Groundwater	Unclassified (Other)	10	0.17	62	WEST YORKSHIRE METROPOLITAN COUNTY COUNCIL	COUNTY HALL, WAKEFIELD, WEST YORKSHIRE
SE 0570 3970	5348	Groundwater	General Industrial	52.27	1.045	345.49	JOHN HAGGAS PLC	PROSPECT NEW MILLS, INGROW, KEIGHLEY
SE 0630 3840	4055	Groundwater	Dom & Agr.	0	0.003	0.914	MR J WOODHEAD	HIGHER HEIGHTS FARM, HAINWORTH, KEIGHLEY, WEST YORKSHIRE.
SE 0640 3650	6634	Groundwater	General Industrial	31	0.45	91	PETS CHOICE LIMITED	HALIFAX ROAD, CULLINGWORTH, BRADFORD, WEST YORKSHIRE
SE 0640 3660	5178	Groundwater	General Industrial	32	0.32	80	WEBBS POULTRY & MEAT GROUP (HOLDINGS) LTD	STANDARD MILLS, CROSS HILLS, KEIGHLEY, WEST YORKSHIRE.
SE 0730 3910	3712	Spring	Dom & Agr.	0	0.007	2.482	A B AINLEY	HEATHER LODGE FARM, HARDEN MOOR, LONG LEE, KEIGHLEY
SE 0750 3830	5768	Spring	Domestic Use Only	1.7	0.002	0.62	MR RONALD EDWARD WATSON & MRS JANICE ELIZABETH WATSON	RYECROFT FARM,RYECROFT,HARDEN,BINGLEY,WEST YORKSHIRE
SE 0760 3910	5192	Groundwater	Dom & Agr.	0.682	0.007	2.49	MR R SHAW-SMITH	CLIFF FARM, LONG LEE,KEIGHLEY, WEST YORKSHIRE
SE03 SW								
SE 0380 3380	2011	Spring	Dom & Agr.	0	0.02	2.482	YORKSHIRE WATER AUTHORITY, WEST RIDING HOUSE, LEEDS.	FAR, MIDDLE AND LOWER ISLE FARM, OXENHOPE, KEIGHLEY
SE 0150 3400	2005	Spring	Dom & Agr.	0	0	0.05	YORKSHIRE WATER PLC	WESTERN DIVSION
SE 0200 3400	2012	Spring	Dom & Agr.	0	0.004	1.11	YORKSHIRE WATER PLC	WESTERN DIVSION
SE 0290 3400	2014	Spring	Dom & Agr.	0	0.003	0.996	YORKSHIRE WATER PLC	WESTERN DIVSION
SE 0350 3400	2010	Spring	Dom & Agr.	0	0.001	0.164	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0273 3428	3267	Spring	Dom & Agr.	0	0.009	3.319	B WILKINSON	ABERDEEN FARM, OXENHOPE,KEIGHLEY
SE 0140 3470	2017	Spring	Dom & Agr.	0	0.007	2.489	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0290 3470	5379	Groundwater	Dom & Agr.	2	0.02	7.121	MR PETER MCMANUS	WEST CROFT HEAD, OFF HEBDEN BRIDGE ROAD, OXENHOPE, WEST YORKSHIRE
SE 0420 3470	4994	Groundwater	Dom & Agr.	0	0.018	6.637	BRUCE GRIGG	BLACKMOOR FARM, OXENHOPE, KEIGHLEY, WEST YORKSHIRE
SE03 NW								
SE 0161 3879	4819	Groundwater	Dom & Agr.	3.637	0.014	4.978	J & P SHARP	TEWITT HALL FARM, OAKWORTH,KEIGHLEY, WEST YORKSHIRE
SE 0200 3530	3622	Spring	Dom & Agr.	0	0.005	1.832	J S HEATON	DUNKIRK, OXENHOPE, KEIGHLEY.
SE 0200 3550	1641	Groundwater	Dom & Agr.	1.364	0.007	2.5	FRANK REDDIHOUGH	MOORIDE LANE FARM, OXENHOPE, KEIGHLEY.
SE 0280 3810	6527	Groundwater	Bottling	2.27	0.02	4.364	BRONTE NATURAL SPRING WATER LTD	P O BOX 99, HAWORTH, WEST YORKSHIRE
SE 0340 3590	5081	Spring	Dom & Agr.	0	0.005	0.682	MRS BETTY CALLAGHAN	NORTH IVES FARM, OXENHOPE, KEIGHLEY, WEST YORKSHIRE
SE 0340 3940	4714	Groundwater	Dom & Agr.	1.82	0.007	2.49	MR E H LUMB	CURE HILL FARM, OAKWORTH,KEIGHLEY, WEST YORKSHIRE
SE 0351 3672	6648	Groundwater	General Industrial	22	0.18	45.5	WEBBS POULTRY & MEATS GROUP (HOLDINGS) LTD	STATION ROAD, CULLINGWORTH, BRADFORD

Table 22 NRA Groundwater and Spring Water Abstraction Data *(continued)*

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SE 0360 3900	2220	Spring	Water Undertaking	0	0.003	1.16	MR J D & MRS D A BEBB	THE BUNGALOW, HIGH EAST ROYD, OAKWORTH, KEIGHLEY, WEST YORKSHIRE
SE 0380 3630	560	Spring	Domestic Use Only	0	0.009	2.273	HOWARTH INDUSTRIAL SAWS LTD	HAWKCLIFFE LEATHER WORKS,HAWORTH,KEIGHLEY,WEST YORKSHIRE
SE 0390 3670	4030	Spring	Dom & Agr.	0	0.002	0.83	DONALD L & JEAN WAITE	MOOREND FARM, BLACKMORE RD, BROW,HAWORTH, KEIGHLEY
SE 0390 3750	6358	Groundwater	General Industrial	27.27	0.364	79.55	WHITAKER FIBRES LIMITED, T/A HAWORTH SCOURING COMPANY	LEES MILL, HAWORTH, KEIGHLEY, WEST YORKSHIRE
SE 0400 3640	6628	Groundwater	Cooling	5	0.05	15	D GILLSON & SONS	NAYLOR HILL QUARRY, BLACKMOOR ROAD, HAWORTH, KEIGHLEY, WEST YORKSHIRE
SE 0410 3620	5568	Groundwater	Dom & Agr.	1	0.005	1.66	BRIAN HAIGH	HIGHER NAYLOR HILL FARM, OXENHOPE, KEIGHLEY
SE 0420 3590	1425	Spring	Dom & Agr.	0	0.005	1.137	JOHN H BURTON	DELF HILL FARM, BLACKMOOR RD, OXENHOPE, KEIGHLEY, WEST YORKSHIRE
SE 0420 3590	4698	Spring	Dom & Agr.	0	0.014	4.546	MR & MRS D J HOPKINS	ROYD HOUSE, ROYD WOOD, OXENHOPE, WEST YORKSHIRE
SE 0420 3719	6660	Groundwater	Commercial Use (pubs etc)	2.27	0.01	3.636	HEYMATT LEISURE LIMITED T/A, THE THREE SISTER HOTEL	BROW TOP ROAD,HAWORTH,NEAR KEIGHLEY, WEST YORKSHIRE
SE 0440 3540	5474	Groundwater	Dom & Agr.	1.1	0.007	2.5	UPWOOD CARAVAN PARK LIMITED	R/O BLACKMOOR ROAD, OXENHOPE, KEIGHLEY
SE 0440 3550	4031	Groundwater	Dom & Agr.	0	0.001	0.332	D M WASLEY	UPWOOD FARM, OXENHOPE, KEIGHLEY, WEST YORKSHIRE
SE 0440 3590	1209	Spring	Dom & Agr.	0	0.005	1.391	R METCALFE	MOUNT PLEASANT FARM, OXENHOPE,KEIGHLEY
SE 0450 3720	787	Spring	Dom & Agr.	0	0.005	0	ARTHUR HOLMES & SON	GREENHEAD FARM, CROSSROADS, KEIGHLEY, WEST YORKSHIRE
SE 0472 3695	6238	Groundwater	Water Undertaking	0.68	0.003	0.909	ANTHONY JACK PEARCE	STUMP CROSS FARM, BROW TOP ROAD, HAWORTH, KEIGHLEY, WEST YORKSHIRE
SE 0478 3629	2810	Groundwater	Dom & Agr.	0	0.002	0.83	HAYDN BANCROFT	BLEAK HOUSE FARM, CROSS ROAD, KEIGHLEY
SE 0480 3690	4680	Groundwater	Dom & Agr.	0	0.002	0.727	ERNEST BRADLEY	STUMP CROSS FARM, CROSS ROADS, KEIGHLEY, WEST YORKSHIRE.
SE 0480 3730	5202	Groundwater	General Industrial	0.546	0.006	2	RHOADES ROBERTSHAW LTD	WICKING CRAG WORKS, CROSS ROAD, KEIGHLEY, WEST YORKSHIRE.
SE 0490 3830	3351	Spring	General Industrial	1.659	0.006	1.409	PAUL WHITFIELD	DAMENS MILL HOUSE, DAMENS, KEIGHLEY, WEST YORKSHIRE
SE04 SW								
SE 0130 4410	303	Spring	Unclassified	2.114	0.015	3.787	SILENTNIGHT LTD	PO BOX 9 BARNOLDSWICK, COLNE, LANCS.
SE 0170 4090	5673	Groundwater	Dom & Agr.	1.2	0.011	4	JOHN SUGDEN	DOBFIELD FARM, LAYCOCK, KEIGHLEY, WEST YORKSHIRE
SE 0180 4180	5015	Groundwater	Dom & Agr.	0	0.009	3.319	MRS C BELL	TODLEY HALL FARM, LAYCOCK, KEIGHLEY, WEST YORKSHIRE
SE 0180 4359	4310	Groundwater	Dom & Agr.	0.455	0.004	0.727	RICHARD F & DOROTHY M H MARRIOT	SUMMER HOUSE FARM, STEETON, KEIGHLEY, WEST YORKSHIRE
SE 0210 4460	1335	Spring	Dom & Agr.	0	0	1.364	RICHARD & MARTHA DAVEY	EASTBURN HOUSE FARM, EASTBURN, KEIGHLEY.
SE 0250 4350	6274	Groundwater	Dom & Agr.	3.63	0.023	5.68	GRAHAM FORT	BRIGHTON HOUSE FARM, WHITELEY HEAD, STEETON, KEIGHLEY, WEST YORKSHIRE
SE 0280 4340	2916	Spring	Water Undertaking	0	0.455	115.923	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0330 4070	6357	Groundwater	Dom & Agr.	1.59	0.016	3.86	JOHN ARTHUR & JANET GARBUTT	WOOD MILL FARM, LAYCOCK, KEIGHLEY, WEST YORKSHIRE
SE 0330 4240	6682	Groundwater	Water Undertaking	0.5	0.002	0.547	KENNETH DUNCAN MCKENZIE & SYLVIA MCKENZIE	HIGHER REDCAR FARM COTTAGE, REDCAR LANE, KEIGHLEY
SE 0330 4240	4538	Spring	Dom & Agr.	0	0.014	3.637	J M BARKER	LOWER REDCAR FARM, STEETON, KEIGHLEY
SE 0340 4290	5578	Groundwater	Dom & Agr.	1.6	0.009	3.319	JOHN MITCHELL BARKER	LOWER REDCAR FARM, STEETON, KEIGHLEY, WEST YORKSHIRE
SE 0370 4230	4087	Groundwater	Dom & Agr.	0	0.014	4.978	ERNEST CRAYSTON	TARN HOUSE FARM, LAYCOCK, KEIGHLEY.
SE 0370 4240	6072	Groundwater	Dom & Agr.	2.72	0.014	3.41	ERNEST GRAYSTON	TARN HOUSE FARM, WHITLEY HEAD, STEETON, KEIGHLEY, WEST YORKSHIRE
SE 0185 4055	6675	Spring	Water Undertaking	1	0.002	0.73	ROY & JACQUELINE MCNAMARA	NEWHOLMES DENE FARM, OAKWORTH, KEIGHLEY
SE04 NW								
SE 0220 4770	2337	Groundwater	Dom & Agr.	1.818	0.014	4.978	M ROBINSON	BLOOMER HILL FARM, SILSDEN MOOR, KEIGHLEY
SE 0240 4750	4431	Groundwater	Water Undertaking	0	0.008	2.821	A J BAINES	BRIDGE HOUSE FARM, SILSDEN, KEIGHLEY
SE 0290 4790	4884	Groundwater	Dom & Agr.	3.637	0.014	4.978	F ROWLING	LOWER HEIGHTS FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE.
SE 0320 4780	5220	Groundwater	Dom & Agr.	0.91	0.007	182	RICHARD JAMES HILL	DIXON GREEN FARM, SISLDEN, KEIGHLEY, WEST YORKSHIRE
SE 0330 4720	4402	Groundwater	Dom & Agr.	0	0.021	7.501	F & M DESERT	LOW BRACKEN HILL FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE.
SE 0360 4710	5935	Groundwater	Commercial Use (pubs etc)	2	0.007	2.5	MRS HAZEL PAULINE APPLEYARD	RAIKES HILL, BRADLEY ROAD, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0360 4740	2374	Groundwater	Dom & Agr.	1.137	0.003	1.246	MALCOLM FORT	RAIKES HEAD FARM, SILSDEN,KEIGHLEY
SE 0370 4830	5240	Groundwater	Commercial Use (pubs etc)	3.2	0.046	16.6	R M PRESTON	DALES BANK FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE

Table 22 NRA Groundwater and Spring Water Abstraction Data *(continued)*

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SE 0370 4860	3297	Groundwater	Dom & Agr.	0	0.002	0.83	J WALKER	FOSTER CLIFFE FARM, SILSDEN MOOR, KEIGHLEY
SE 0390 4770	219102	Groundwater	Dom & Agr.	1.818	0.009	3.319	MR M R LERMAN	HAYHILLS FARM SOUTH, HAYHILLS LANE, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0480 4880	5829	Groundwater	Dom & Agr.	3	0.028	10	RODERICK CRANE	OLD HALL FARM, BRADLEY ROAD, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0490 4840	841	Groundwater	Water Undertaking	2.73	0.031	11.37	GEORGE HARRISON	CRINGLES PARK, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0490 4900	5256	Groundwater	Dom & Agr.	1.137	0.011	4.103	JOSEPH LEONARD BECKWITH	THE BUNGALOW, MIDDLE MARCHUP FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0212 4955	2034	Groundwater	Dom & Agr.	0	0.014	4.978	K H THROUP	HIGHER HOUSE FARM, SILSDEN MOOR, NR. KEIGHLEY
SE 0260 4890	2191	Groundwater	Dom. & Agr.	1.818	0.014	5.001	MR & MRS J FORT	HIGH BRACKEN HILL FARM, SILSDEN, KEIGHLEY
SE 0300 4850	412401	Groundwater	Dom & Agr.	0	0.032	0	SILSDEN MOOR WATER COMMITTEE	C/O R J HILL, DIXON GREEN, SILSDEN, KEIGHLEY
SE 0250 4810	4167	Groundwater	Dom & Agr.	0	0.009	3.319	MALCOLM WAITE	HEIGHTS FARM, SILSDEN MOOR, KEIGHLEY
SE 0370 4870	5008	Groundwater	Dom & Agr.	0	0.014	4.978	MESSRS F & M WAINMAN	FOSTER CLIFF FARM, SILSDEN MOOR, KEIGHLEY
SE 0350 4950	5286	Groundwater	Dom & Agr.	0.682	0.007	2.487	N S BREARE & SONS	COWBURN FARM, SILSDEN, KEIGHLEY
SE 0410 4960	4518	Spring	Dom & Agr.	0	0.007	2.489	H COCKSHOTT	WOOFA BANK FARM, SILSDEN, KEIGHLEY
SE04 SE								
SE 0500 4480	6641	Spring	Water Undertaking	4	0.02	6	HOLDEN SPRINGS LIMITED	HOLDEN BECK BARN, HAINSWORTH ROAD, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0570 4030	1620	Groundwater	Cooling/Gen Ind.	31.822	0.546	114	TIMOTHY TAYLOR & CO LTD	KNOWLE SPRING BREWERY, KEIGHLEY, WEST YORKSHIRE.
SE 0600 4270	5888	Groundwater	General Industrial	50	0.909	105	HERBERT ROBERTS LTD	ROYD WORKS, ROYD LANE, KEIGHLEY, WEST YORKSHIRE
SE 0640 4150	6596	Groundwater	Cooling	2	0.008	2.92	G FARRAR QUARRIES LIMITED	THE WORKS, BRADFORD STREET, KEIGHLEY, WEST YORKSHIRE
SE 0640 4200	648	Groundwater	General Industrial	9.092	0.218	54.552	THE RUSTLESS IRON CO.LTD	LAWKHOLME LANE, KEIGHLEY, WEST YORKSHIRE
SE 0640 4320	4041	Spring	Dom & Agr.	0	0.014	4.978	MICHAEL HOLMES	GRANGE FARM, HARROGATE
SE 0670 4220	6454	Groundwater	Bottling	23.375	0.187	68.19	COLIN MYLES & AUDREY LYNNE WHITELEY,T/A,W WHITELEY & SONS	KEIGHLEY ABATTOIR, HARD INGS ROAD, KEIGHLEY, WEST YORKSHIRE
SE 0680 4220	5126	Groundwater	Cooling	91	0.727	227	ONDURA LIMITED	ALSTON WORKS, ALSTON ROAD, KEIGHLEY, WEST YORKSHIRE
SE 0700 4360	2911	Spring	Water Undertaking	0	0.455	13.365	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0720 4130	835	Groundwater	General Industrial	11.365	0.091	23.639	FOULDS LTD	PARKWOOD STREET, KEIGHLEY
SE 0950 4170	6537	Groundwater	Dom/Agr./Irrig	0	0	0	DAVID HERBERT HEATON	NURSERY FARM, EAST MORTON, KEIGHLEY, WEST YORKSHIRE
SE 0980 4050	5619	Groundwater	General Industrial	6.8	0.091	33.182	PARKMOUNT ESTATE CO (ALLERTON) LIMITED	R/O GAZEBY HALL, BECK LANE, ALLERTON, BRADFORD
SE04 NE								
SE 0507 4619	6449	Groundwater	Water Undertaking	1.36	0.009	0.909	JOHN NEWNS	SYCAMORE FARM, BRUNTHWAITE, SILSDEN, WEST YORKSHIRE
SE 0518 4622	6331	Groundwater	Water Undertaking	1.82	0.003	0.996	ERNEST HARRY CHAMLEY	3 THE TERRACE, BRUNTHWAITE, SILSDEN,NEAR KEIGHLEY
SE 0540 4690	3609	Groundwater	Dom & Agr.	2.046	0.018	6.546	F H & N BELL	HIGH SWARTHA FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE.
SE 0548 4527	4768	Groundwater	Dom & Agr.	2.273	0.014	5.001	RONALD EMMETT	HOLDEN PARK FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0549 4517	482002	Groundwater	Domestic Use Only	0	0.009	3.32	E BOOTHMAN	HOWDEN PARK FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0549 4527	482001	Groundwater	Dom & Agr.	0	0.009	3.319	E BOOTHMAN	HOWDEN PARK FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE.
SE 0550 4600	5494	Groundwater	Spray Irrigation	9	0.054	5.35	TRUSTEES OF SILSDEN GOLF CLUB	C/O G DAVEY, HIGH BRUNTHWAITE,S ILSDEN
SE 0580 4590	4672	Groundwater	Dom & Agr.	2.273	0.014	4.978	J R HARPER	TOMLING COTE FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE.
SE 0600 4680	2788	Spring	Water Undertaking	0	0.007	2.488	DONALD PRATT	TOWNHEAD FARM, BRUNTHWAITE, SILSDEN, KEIGHLEY
SE 0620 4780	4433	Groundwater	Dom & Agr.	1.8	0.018	6.64	MRS L LAYCOCK	HANG GOOSE FARM, SILSDEN, KEIGHLEY.
SE 0620 4780	5621	Groundwater	Dom & Agr.	1.5	0.002	0.409	DAVID WILLIAM SMART & JUDITH ANNE SMART	CHYNHALLS, LIGHTBANK LANE, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0740 4590	3607	Groundwater	Dom & Agr.	2.273	0.007	2.5	R M CRABTREE	TURNALANE FARM, ADDINGHAM,SKIPTON
SE 0510 4960	451802	Spring	Dom & Agr.	0	0.004	1.41	H COCKSHOTT	WOOFA BANK FARM, SILSDEN, KEIGHLEY
SE13 SE								
SE 1690 3020	5318	Groundwater	Spray Irrigation	4.55	0.046	2.27	WEST BOWLING GOLF CLUB	NEWHALL HALL, ROOLEY LANE, BRADFORD, WEST YORKSHIRE
SE 1610 3080	415	Groundwater	General Industrial	13.638	0.273	65.462	DHC (BRADFORD) LTD	CENTRAL MILLS, RAYMOND STREET, WEST BOWLING, BRADFORD
SE 1586 3105	5719	Groundwater	Cooling/Gen Ind.	15	0.12	28.8	FRANK MONKMAN LIMITED	MARSHFIELD MILLS, MARSH STREET, BRADFORD
SE 1679 3147	5547	Groundwater	Cooling/Gen Ind.	68.2	1.637	45.46	CYANAMID LIMITED	BOWLING PARK DRIVE, BRADFORD, WEST YORKSHIRE
SE 1623 3193	184	Groundwater	General Industrial	22.73	0.546	29.549	BOWLING MILLS COMBING CO. LTD	BOWLING MILLS, 5 BOWLING OLD LANE, BRADFORD 5
SE 1790 3260	5230	Groundwater	General Industrial	63.6	0.818	364	JOSEPH DAWSON LIMITED	CASHMERE WORKS,BECK STREET, BRADFORD, WEST YORKSHIRE
SE 1790 3260	6219	Groundwater	General Industrial	45.46	0.568	136.38	BENSON TURNER (DYERS) LTD	MOUNT STREET, BRADFORD, WEST YORKSHIRE

Table 22 NRA Groundwater and Spring Water Abstraction Data *(continued)*

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SE 1620 3270	97	Groundwater	Cooling	43.187	1.036	378.318	GREATCAUSE LTD	BRADFORD ICE RINK, LITTLE HORTON LANE, BRADFORD, WEST YORKSHIRE
SE 1570 3310	4848	Groundwater	General Industrial	9	0.216	54.5	ROBERT JOWITT & SONS LTD	153 SUNBRIDGE ROAD, BRADFORD 1
SE 1610 3460	5866	Groundwater	General Industrial	22.7	0.181	54.55	WEST YORKSHIRE FELLMONGERS LTD	VALLEY ROAD, BRADFORD, WEST YORKSHIRE
SE13 NW								
SE 1040 3675	4189	Spring	Dom & Agr.	0	0.01	3.65	G & J WARIN	MARCH COTE FARM, COTTINGLEY, BINGLEY, WEST YORKSHIRE.
SE 1000 3710	6103	Groundwater	Dom & Agr.	1.81	0.009	2.27	JAMES EDWARD KUNZ	GAZEBY HALL, ALLERTON, BRADFORD, WEST YORKSHIRE
SE 1470 3800	5448	Groundwater	Cooling	68	1.63	364	S JEROME & SON (HOLDINGS) LIMITED	VICTORIA MILLS, SHIPLEY, YORKSHIRE
SE 1100 3820	4355	Groundwater	Dom/Agr./Irrig	0	0.023	0.136	JOYCE DEAN	30 ASHFIELD TERRACE, BINGLEY
SE 1110 3820	1139	Groundwater	Spray Irrigation	72.736	0.455	2.728	R LEVRIER	20 WOODSIDE DRIVE, COTTINGLEY, BINGLEY, WEST YORKSHIRE.
SE 1030 3840	5781	Groundwater	Water Undertaking	1.5	0.008	3	NICHOLAS PRICE & CAROLE LARSEN	3 BECKFOOT MILL, BECKFOOT LANE, BINGLEY, WEST YORKSHIRE
SE 1130 3920	2840	Groundwater	General Industrial	13.638	0.327	100.012	ANDERTON INTERNATIONAL LIMITED	PO BOX 6, BINGLEY, YORKSHIRE
SE 1085 3925	6111	Groundwater	General Industrial	3.05	0.049	15.59	GEO. ACKROYD JNR LTD	STANLEY MILLS, WHITLEY STREET, BINGLEY, WEST YORKSHIRE
SE 1090 3930	1954	Groundwater	General Industrial	9.092	0.036	9.092	JOHN WHITE & SONS	CLYDE STREET, BINGLEY, WEST YORKSHIRE
SE 1370 3930	5766	Spring	Commercial Use (pubs etc)	5	0.016	1.275	MOORE VALLEY LEISURE LIMITED	MILL LANE, HAWKSWORTH, GUISELEY
SE13 SW								
SE 1010 3060	687	Groundwater	General Industrial	36.368	0.727	181.84	JOHN FOSTER & SONS LTD	BLCK DYKE MILLS, QUEENSBURY, BRADFORD
SE 1440 3490	781	Groundwater	General Industrial	26.376	0.636	193.205	LISTER & CO LTD	MANNINGHAM MILLS, BRADFORD
SE13 NE								
SE 1500 3550	1417	Spring	Domestic Use Only	0	0.002	0.832	TURF MOTORS OF FRIZINGHALL LTD	TURF GARAGE, FRIZINGHALL, BRADFORD 9.
SE 1662 3897	6450	Groundwater	Pond level maintenance	1.82	0.009	2.273	N D MARSTON LIMITED	MARSTON HOUSE, OTLEY ROAD, SHIPLEY, WEST YORKSHIRE
SE 1860 3950	6123	Groundwater	Water Undertaking	20	0.24	87.6	YORKSHIRE WATER PLC	2 THE EMBANKMENT, SOVREIGN STREET, LEEDS
SE 1710 3990	78902	Groundwater	General Industrial	5.228	0.127	88.65	ALBERT BARKER (ESHOLT) LTD	ESHOLT, SHIPLEY, WEST YORKSHIRE
SE14 SW								
SE 1160 4090	4284	Groundwater	Dom & Agr.	2.045	0.007	2.489	MRS A M CLARK	HILL TOP FARM, ELDWICK, BINGLEY.
SE 1480 4120	6307	Groundwater	Domestic Use Only	1.13	0.009	1.36	SHIPLEY & BAILDON DISTRICT SCOUT COUNCIL C/O COLIN JAMES DANIEL	16 FERNBANK DRIVE, BAILDON, BRADFORD
SE 1270 4210	1525	Spring	Water Undertaking	0	0.023	8.183	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 1310 4220	4854	Groundwater	Dom & Agr.	0	0.007	2.487	HARVEY SMITH	CRAIGLANDS FARM, HIGH ELDWICK, BINGLEY, WEST YORKSHIRE
SE 1000 4270	2910	Spring	Water Undertaking	0	0.002	0.682	YORKSHIRE WATER PLC	WESTERN DIVISION
SE14 NW								
SE 1360 4740	1222	Groundwater	Dom & Agr.	1.137	0.003	1.25	MALCOLM FORT	RAIKES HEAD FARM, SILSDEN, KEIGHLEY.
SE14 SE								
SE 1690 4030	89202	Groundwater	Cooling/Gen Ind.	202.297	1.618	90.92	WILLIAM DENBY & SONS LTD	TONG PARK MILLS, SHIPLEY, WEST YORKSHIRE.
SE23 SW								
SE 2100 3120	5306	Groundwater	Dom & Agr.	2.73	0.027	9.96	MESSRS C K & J S HANSON	SCHOLEBROOK FARM, TONG, BRADFORD, WEST YORKSHIRE
SE23 NW								
SE 2005 3975	3308	Spring	Domestic Use Only	0	0.023	8.3	BRADFORD METROPOLITAN COUNCIL	CITY HALL, BRADFORD 1, WEST YORKSHIRE
			Totals	1365.399	19.883	4583.432		

Figure 23 NRA Surface Water Abstraction Data.

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SD93 NE								
SD 9870 3940	2928	Surface	Water Undertaking	0	0	818.28	YORKSHIRE WATER PLC	WESTERN DIVISION
SD 9910 3690	6447	Surface	Domestic Use Only	0.16	0.002	0.227	MR BARROWS, C/O THE PONDEN CENTRE	LOWER SLACK FARM, PONDON WATER, STANBURY, HAWORTH
SD 9950 3730	5129	Surface	Water Undertaking	0	6.82	1246	YORKSHIRE WATER	WESTERN DIVISION
SD 9950 3740	313602	Surface	General Industrial	0	0.005	1.137	PONDEN MILL LTD	CRAVENDALE HOUSE, HARGREAVES STREET, CROSS HILLS, KEIGHLEY
SE03 SW								
SE 0170 3440	4647	Surface	Water Undertaking	0	5.319	381.864	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0290 3450	4648	Surface	Water Undertaking	0	6.137	450.054	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0470 3380	6694	Surface	Domestic use only	1.09	0.001	0.4	HALIFAX BUILDING SOCIETY	NORTH END PROPERTIES, PO BOX 181, BRADFORD
SE03 NW								
SE 0140 3690	2918	Surface	Water Undertaking	0	0	2159.35	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0180 3520	3621	Surface	Water Power	1136.5	11.365	2591.22	J DEWHIRST & CO	DUNKIRK MILL, OXENHOPE, KEIGHLEY.
SE 0240 3520	3501	Surface	General Industrial	0	0	0.091	BROOKS MEETING MILLS LTD	BROOKS MEETING MILL, OXENHOPE, NR KEIGHLEY, WEST YORKSHIRE.
SE 0260 3780	5207	Surface	Water Undertaking	0	0	0	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0360 3810	1768	Surface	Water power/Ind/Cooling	0	2.361	591.03	J,J R & J J SUTCLIFFE HEATON T/A DEWHIRST & CO	DUNKIRK MILLS, OXENHOPE, KEIGHLEY
SE 0393 3753	5555	Surface	Unclassified Combs.	0	0	0	G WHITAKER & COMPANY LIMITED, T/A HAWORTH SCOURING CO.	LEES MILL, HAWORTH, KEIGHLEY, WEST YORKSHIRE
SE 0470 3740	5750	Surface	Unclassified (Other)	1100	26	455	WEST YORKSHIRE METROPOLITAN DISTRICT COUNCIL	COUNTY HALL,WAKEFIELD,WEST YORKSHIRE
SE03 SE								
SE 0550 3300	4645	Surface	Water Undertaking	0	0	6214.382	YORKSHIRE WATER PLC	WESTERN DIVISION
SE 0690 3220	5467	Surface	Unclassified (Other)	0	0	0	DENHOLME VELVETS LTD	R/O FORESIDED MILL, DENHOLME CLOUGH, DENHOLME, BRADFORD
SE03 NE								
SE 0530 3920	177	Surface	General Industrial	45.46	0.436	121.651	BRITISH MOHAIR SPINNERS LTD	GROVE MILLS, INGROW, KEIGHLEY, WEST YORKSHIRE
SE 0560 3740	5860	Surface	Unclassified (Other)	0	0	4.12	WEST YORKSHIRE METROPOLITAN COUNTY COUNCIL	COUNTY HALL,WAKEFIELD,WEST YORKSHIRE
SE 0640 3700	1263	Surface	General Industrial	0	0.03	5.683	YORKSHIRE LIFT SERVICES LTD	ELLAR CARR WORKS, ELLAR CARR ROAD, CULLINGWORTH, WEST YORKS
SE 0835 3826	6004	Surface	Cooling/Gen Ind.	1.42	0.034	7.67	ELLISON CIRCLIPS LTD	HARDEN MILLS, HARDEN, BINGLEY, WEST YORKSHIRE
SE04 NW								
SE 0400 4570	2316	Surface	General Industrial	0	0	0.136	WEAVESTYLE	RIVERSIDE, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0419 4592	2450	Surface	General Industrial	0.045	0	0.057	NAYLOR MYERS LIMITED	IMITEDLES LANE, LEEDS ROAD, HUDDERSFIELD
SE 0490 4840	451804	Surface	Dom & Agr.	0	0.004	1.41	H COCKSHOTT	WOOFA BANK FARM, SILSDEN, KEIGHLEY, WEST YORKSHIRE
SE 0450 4750	4642	Surface	Water Undertaking	56.825	1.364	272.76	YORKSHIRE WATER PLC	WESTERN DIVISION
SE04 SW								
SE 0460 4100	1470	Surface	Steam Raising/Sanitation	0	0.01	2.5	MESSRS J STELL & SONS	
SE04 SE								
SE 0550 4340	1279	Surface	Spray Irrigation	6.36	0.038	2.54	KEIGHLEY GOLF CLUB C/O C L HODGE	HOWDEN PARK, UTLEY, KEIGHLEY
SE 0600 4380	5698	Surface	Spray Irrigation	0	0	0	THE TRUSTEES OF THE RIDDLESDEN GOLF CLUB	HOWDEN ROUGH, ELLAMWOOD ROAD, RIDDLESDEN, KEIGHLEY
SE 0650 4110	3768	Surface	Cooling/Gen Ind.	10.229	0.114	31.822	ONDURA LTD	HARD INGS RD, KEIGHLEY, WEST YORKSHIRE.
SE 0705 4160	71	Surface	General Industrial	20.46	0.161	26.78	ATKINSON DYEING CO. LTD	DALTON DYEWORKS, KEIGHLEY.
SE 0700 4240	978	Surface	General Industrial	1.55	0.037	13.7	MAGNET JOINERY LTD	WHITLEY STREET, BINGLEY, WEST YORKSHIRE
SE 0710 4150	213	Surface	General Industrial	0	0	0	SIR JAMES HILL & SONS LTD.	MELBOURNE MILLS, DALTON LANE, KEIGHLEY.
SE 0710 4160	6679	Surface	Cooling	2	0.015	3.3	LEACH & THOMPSON LTD.	CHAPEL FOUNDRY, DALTON LANE, KEIGHLEY
SE 0620 4300	390	Surface	General Industrial	0	0.227	0	HERBERT ROBERTS LTD	ROYD WORKS, BEECHCLIFFE, KEIGHLEY, WEST YORKSHIRE

Figure 23 NRA Surface Water Abstraction Data *(continued)*

INDEX REF Grid. Ref.	INDEX REF App No.	(code) Source Type	(code) General Use	(m3/hr) Lic.Hour	(tcmd) Lic.Day	(TCMA) Lic.Year	(text) Lic.Holder Name	(text) Lic.Holder Addrss
SE04 NE								
SE 0720 4580	4640	Surface	Water Undertaking	2532.122	30.413	1245.604	YORKSHIRE WATER PLC	WESTERN DIVISION.
SE12 NE								
SE 1680 2830	5809	Surface	Unclassified (Other)	0	0	8.6	CITY OF BRADFORD METROPOLITAN COUNCIL	CITY HALL, BRADFORD, WEST YORKSHIRE
SE13 SW								
SE 1200 3470	3843	Surface	Spray Irrigation	5.001	0.12	1.441	WEST BRADFORD GOLF CLUB LTD.	CHELLOW GRANGE, BRADFORD 9.
SE 1350 3310	5099	Surface	General Industrial	36.362	0.873	227.273	WOOLCOMBERS LIMITED	PO BOX 227, FAIRWEATHER GREEN MILLS, THORNTON ROAD, BRADFORD
SE13 NW								
SE 1030 3850	4275	Surface	Spray Irrigation	5.455	0.064	3.182	SHIPLEY GOLF CLUB	BECKFOOT, BINGLEY, WEST YORKSHIRE
SE 1090 3511	6189	Surface	Unclassified (Other)	0	0	0	KEIGHLEY ANGLING CLUB	4 COMPEIGNE AVENUE, RIDDLESDEN, KEIGHLEY, WEST YORKSHIRE
SE 1490 3800	674	Surface	Cooling	54.552	1.309	63.644	S JEROME & SONS (HOLDINGS) PLC	VICTORIA WORKS, SHIPLEY, WEST YORKSHIRE
SE13 NE								
SE 1710 3990	78901	Surface	General Industrial	34.095	0.341	88.647	ALBERT BARKER (ESHOLT) LTD	ESHOLT, SHIPLEY, WEST YORKSHIRE
SE 1880 3530	4374	Surface	Unclassified (Other)	81.828	0.982	190.932	BERRY & MARSHALL (BOLTON WOODS) LTD	FAGLEY LANE, ECCLESHILL, BRADFORD
SE14 SW								
SE 1000 4121	5147	Surface	Unclassified (Other)	2	0.007	0.355	BRITISH WATERWAYS	WILLOW GRANGE, CHURCH ROAD, WATFORD
SE 1130 4060	6191	Surface	Pond level maintenance	25	0.6	219	DYKE BROTHERS (LAKES) LTD	DERBY SQUARE, WINDEMERE, CUMBRIA
SE 1180 4210	1510	Surface	Water Undertaking	0	0	2727.6	YORKSHIRE WATER PLC	WESTRN DIVISION
SE 1360 4200	1509	Surface	Water Undertaking	0	0	909.2	YORKSHIRE WATER PLC	WESTERN DIVION
SE14 SE								
SE 1650 4020	89201	Surface	Cooling/Gen Ind.	0	13.638	772.8	WILLIAM DENBY & SONS LTD	TONG PARK MILLS, SHIPLEY, WEST YORKSHIRE.
SE24 SW								
SE 2070 4050	7201	Surface	General Industrial	136.38	1.637	363.68	NAYLOR, JENNINGS & CO.LTD	GREEN LANE DYEWORKS, YEADON, LEEDS
SE 2270 4170	5778	Surface	Unclassified (Other)	0	0	0	CITY OF BRADFORD MET COUNCIL, THE LEEDS & BRADFORD AIRPORT JT COMMITTEE	CITY HALL,BRADFORD,WEST YORKSHIRE
			Totals	5294.894	110.464	22225.122		

14.5 Sandstone Properties Building Stone Study

The study aimed to provide information on the physical properties of a wide stratigraphic range of sandstones from both the Millstone Grit and Coal Measures. Prior to this study little of such information was publicly available. Samples of sandstone were taken from former quarry sites across the District.

The following tests were carried out on each sample by the University of Bradford, using the general guidance of methods published by the International Society for Rock Mechanics (Brown, 1981):

1) Index Properties

- Dry density — The ratio of the mass of the sample to its volume
- Apparent Porosity — Pore space is calculated from the difference in dry and saturated weights of the specimen
- Specific gravity — The ratio of the weight of the sample to the weight of an equal volume of water

2) Strength Properties

- Uniaxial Compressive Strength (UCS)
- Brazilian Tensile Strength
- Point Load Strength Index — This is a simplification of the UCS test which can give a rapid indication of rock strength

In addition the following test was carried out by BGS using methods detailed in BRE Digest 269 (BRE, 1989) and Ross and Butlin (1989):

3) Chemical Properties

- Acid Immersion — Grain size was recorded using the Udden-Wentworth scale and colour changes using the Munsell scheme. After testing samples were assessed for grain disaggregation and fracturing based on a pass/fail criteria, with a maximum number of passes of 6 per sample tested.

The results of the study are summarised in Tables 24 and 25 and discussed below.

Index properties

The values for dry density range from 1974.54 kg/m^3 for the Elland Flags (sample 12) to 2407.72 kg/m^3 for the Greenmoor Rock (sample 1), with typical values in the region of 2300 kg/m^3. There is an almost linear relationship between dry density and porosity, suggesting that density is varying as a function of pore volume rather than mineralogy. The more dense rocks (typically Coal Measures) tend to be finer grained with quartz overgrowths and grain welding. The less dense rocks (typically Millstone Grit) are much coarser grained and display less quartz cementation, but with a significant proportion of pore spaces filled with clay minerals.

Porosity values range from 7.47% for the Woodhouse Grit (sample 28) to 26.26% for the Elland Flags (sample 12), with a general cluster between 10% and 17%. The very high value for sample 12 is unusual for a sandstone and suggests the sample has undergone dissolution or alteration. Visible porosity was only identified by microscopic examinations in the Middleton Grit (sample 23a) and Brocka Bank Grit (sample 24). The apparent porosity values may thus be intergranular voids partially filled with secondary clay minerals rather than voids filled with water.

Strength properties

The uniaxial compressive strength values range from 13.36 MPa for the Kinderscout Grit (sample 25) to 108.27 MPa for the Stanningley Rock (sample 8). The majority of samples lie between an upper strength boundary of approximately 60 MPa and a lower boundary of approximately 25 MPa. High strengths were recorded for the Stanningley Rock (sample 8), Elland Flags (sample 11) and Kinderscout Grit (sample 17a). The strength of samples 8 and 11 is attributed to the very fine grain size and the presence of a fine lamination, which was oriented perpendicular to the axis of loading. It is important to note that these tests were carried out on fully saturated samples. Tests on Elland Flags in Bradford show that saturated compressive strengths can be as much as 60% lower than the oven dried strengths (Snee, 1995). The values should thus be considered as minimum strengths.

Tensile strength values range from 0.46 MPa for the Kinderscout Grit (sample 25) to 10.58 MPa, also for the Kinderscout Grit (sample 17b). The tensile strength has a mean ratio of 10% of the compressive strength of the samples.

Evidence for strength anisotropy can be found in the relationship between the axial and diametrical point load strength index. If a rock is isotropic these values should be the same. Very slight anisotropy is characterised by axial and diametrical ratios up to 2. The overall trend in the samples is for ratios between 1.0 and 1.4, which suggests that there is only a slight influence from the sedimentary fabric and the samples may be considered as isotropic.

Chemical properties

Many of the samples showed subtle and even colour changes following testing which would not be considered detrimental in the use of this stone for building purposes. However, several samples showed degrees of patchy colour alteration which would probably be considered unsightly in a building stone. The Clifton Rock (sample 4) developed a marked black discolouration along fractures, whereas the Elland Flags (samples 7 and 10), Rough Rock (sample 15), Addingham Edge Grit (sample 16) and Marchup Grit (samples 18, 19 and 20) displayed prominent orange spots.

Disaggregation of grains from slab corners and edges was a problem with the Elland Flags (sample 12), Kinderscout Grit (samples 25 and 27) and to a lesser degree the Marchup Grit (sample 19). Disaggregation is more of a problem with the coarse- to very coarse-grained sandstones. Sample 12 is anomalous, probably due to the sample being weathered.

Fracturing of slabs was a particular problem with the Elland Flags (sample 11), Clifton Rock along laminae (sample 4) and Brocka Bank Grit (sample 24). Calcite is not present in any of these samples and it is suggested that fracturing may be the result of swelling of clay minerals.

Samples which have maintained their integrity during the test, include the 48 Yard Rock (sample 13), Addingham Edge Grit (samples 16, 18 and 26), Marchup Grit (sample 20) and Woodhouse Grit Flags (sample 28).

Summary

The tests show that, although the geomechanical properties

Table 24 Summary of laboratory test results.

Sample Number*	Name	Uniaxial compressive strength (MPa)	Tensile strength (MPa)	Axial point load strength (MPa)	Diametrical point load strength (MPa)	Saturation content (%)	Dry density (kg/m^3)	Porosity (%)	Specific gravity
1 (CNW9)	Greenmoor Rock	54.64	6.10	3.61	1.69	3.97	2407.72	8.21	2.41
2 (CNW10)	Grenoside Sandstone	49.97	1.94	3.13	2.22	4.87	2263.42	13.72	2.26
3 (CNW11)	Clifton Rock	29.08	3.87	2.13	2.13	6.66	2203.93	17.12	2.20
4 (CNW12)	Clifton Rock	43.95	1.88	2.81	2.31	6.27	2201.35	17.08	2.20
5 (CNW13)	Unnamed	42.42	2.98	1.59	1.75	4.57	2324.84	12.01	2.32
6 (CNW14)	Elland Flags	41.02	3.99	3.13	1.69	3.79	2371.87	11.27	2.37
7 (CNW15)	Elland Flags	23.98	2.34	2.11	0.90	4.22	2358.87	11.64	2.36
8 (CNW16)	Stanningley Rock	108.27	9.61	8.76	8.26	3.14	2351.21	8.15	2.35
9 (CNW17)	Rough Rock	38.38	5.01	1.81	0.70	4.74	2332.89	11.88	2.33
10 (CNW18)	Elland Flags	56.27	5.02	3.53	3.30	3.93	2326.83	11.14	2.33
11 (CNW19)	Elland Flags (lower leaf)	95.98	7.10	5.89	5.54	2.85	2395.95	9.40	2.40
12 (CNW20)	Elland Flags (upper leaf)	17.00	0.72	0.72	0.50	13.83	1974.54	26.26	1.97
13 (CNW21)	48 Yard Rock	46.63	3.63	2.39	2.06	7.09	2191.91	17.24	2.19
14 (CNW22)	48 Yard Rock	46.96	4.00	3.25	2.79	5.27	2294.73	12.84	2.29
15 (CNW23)	Rough Rock	37.25	1.99	2.06	1.78	4.56	2308.77	12.94	2.31
16a (CNW24)	Addingham Edge Grit	23.91	2.39	1.38	1.47	6.35	2254.98	14.65	2.25
16b (CNW24)	Addingham Edge Grit	18.96	1.66	0.94	1.01	6.21	2331.13	11.65	2.33
17a (CNW25)	Kinderscoutian Grit	91.25	10.58	4.88	5.53	3.94	2393.77	9.25	2.39
17b (CNW25)	Kinderscoutian Grit	32.33	5.63	2.39	2.33	6.56	2232.80	15.58	2.23
18 (CNW26)	Marchup Grit	28.25	3.00	0.15	1.20	5.47	2303.31	11.84	2.30
21 (CNW29)	Nesfield Sandstone	50.82	4.74	2.05	2.52	5.57	2281.89	13.35	2.28
22 (CNW30)	Middleton Grit	53.69	3.86	1.90	1.67	6.42	2237.53	15.38	2.24
23a (CNW31)	Middleton Grit	40.99	4.19	2.53	1.75	5.48	2268.14	14.31	2.27
23b (CNW31)	Middleton Grit	50.48	5.41	2.88	2.06	3.92	2371.98	8.65	2.37
24 (CNW32)	Brocka Bank Grit	23.95	5.77	5.32	4.56	6.47	2347.62	11.51	2.35
25 (CNW33)	Kinderscoutian Grit	13.36	0.46	0.47	0.39	8.03	2166.55	17.73	2.17
26 (CNW34)	Addingham Edge Grit	35.72	3.39	1.96	1.75	5.59	2297.94	12.72	2.30
27 (CNW35)	Kinderscoutian Grit	26.58	2.88	1.51	1.20	4.87	2321.74	12.10	2.32
28 (CNW36)	Woodhouse Grit Flags	54.97	6.71	5.20	5.04	2.85	2397.88	7.47	2.40

* The first number is the laboratory system. The number in brackets is the BGS system.

Table 25 Acid immersion tests for the sandstone building stone properties study.

Sample No.		Grain Size	Colour (initial)	Colour (alteration)	Disaggre-gation*1	Fractures*1	Passes*2
1	CNW 9	Fine	Yellowish grey	Light to medium light grey	0	2 (minor)	4
4	CNW12	Fine	Pale yellowish orange	Light brown and black along fractures	1	3 (// to bedding)	3
5	CNW 13	Very fine	Yellowish grey	Medium light grey	0	1	5
7	CNW15	Fine	Yellowish grey	Dusky yellow brown spots	0	2	4
8	CNW16	Fine	Medium light grey	Medium to medium dark grey	0	2	4
9	CNW17	Coarse	Very pale orange	Very pale orange	1	0	5
10	CNW18	Very fine	Very pale orange	Light orange brown spot	0	2 (minor)	4
11	CNW19	Very fine	Pale yellow green	Light olive grey	0	6 (major)	0
12	CNW20	Fine	Moderate brown	Very pale orange	6	1	0
13	CNW21	Fine	Very pale orange	Slight orange discolouration	0	0	6
15	CNW 23	Fine	Greyish orange	Very pale orange with orange spots	0	2	4
16A	CNW24	Coarse to very coarse	Pale yellow orange	Very pale orange with orange spots	0	0	6
16B	CNW24	Medium to very coarse	Greyish orange to very pale orange	Very pale orange	0	0	6
17	CNW25	Fine	Very pale orange	Light grey to dark yellow orange	0	2 (at edges)	4
17B	CNW 25	Coarse	Very pale orange	Medium grey	1	0	5
18	CNW26	Medium	Very pale orange	Very light grey with orange spot	0	0	6
19	CNW27	Coarse	Greyish orange	Very pale orange with greyish orange patches	2	0	4
20	CNW28	Medium	Greyish orange to Very pale orange	Very light grey to very pale orange with orange patches	0	0	6
21	CNW29	Fine	Greyish orange	Very pale orange with greyish orange patches	0	1	5
22	CNW30	Fine	Very pale orange	Very pale orange greyish orange	1	0	5
23	CNW31	Fine to medium	Very pale orange	Light grey to greyish orange	0	2	4
24B	CNW32	Fine to medium	Very pale orange greyish orange	Greyish orange to moderate brown	0	3 (common)	3
25	CNW33	Coarse to very coarse	Pale yellowish brown	Greyish orange	6	0	0
26	CNW34	Coarse	Very pale orange	Greyish orange	0	0	6
27	CNW35	Coarse to very coarse	Greyish orange	Very pale orange to light brown	3	0	3
28 CNW36		Fine	Very pale orange	Very pale orange	0	0	6

*1 Number of failures from a total of 6.
*2 Total number of passes from a maximum of 6.

can vary significantly between stratigraphic units, most of the rocks display several important requirements for mineral quality sandstone. These are as follows:

- They are dense
- They have low porosity
- They are sufficiently strong for load bearing but soft enough to be shaped for architectural purposes

In very general terms, the stronger, or more competent rocks tend to be finer grained with a high quartz content, whereas less competent rocks tend to be coarser grained and show evidence of alteration and secondary growth of clay minerals. In addition, the rocks are isotropic under a variety of loading situations.

These results should only be used as a guide to the properties of sandstones in the District. It is common for sandstones to show wide variations in their physical and chemical properties within the same quarry. It is therefore important that prior to development of a new site that a number of samples are tested, using the suite of tests described above, in order to ascertain the suitability of sandstones at specific sites for a particular purpose.

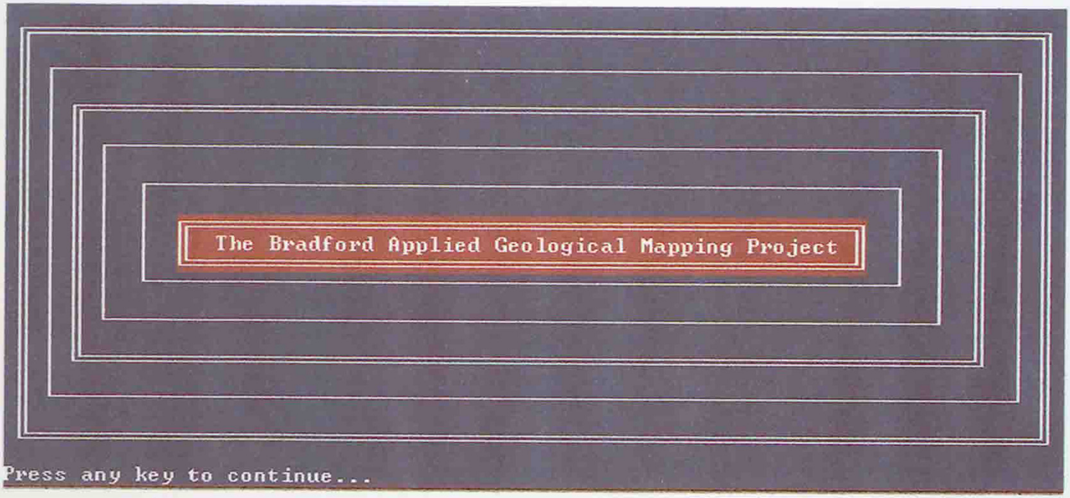


Figure A1 — Initial screen

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.

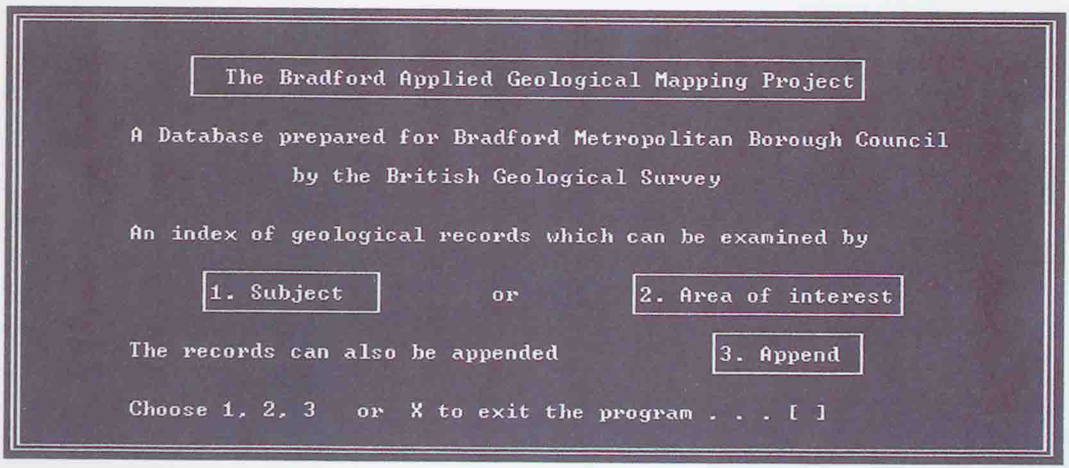


Figure A2 — Main screen

14.6 Computer databases user guide

The system has been designed to operate on an IBM compatible computer running dBase III+ software, though it can be readily imported into Microsoft Access. It consists of five distinct databases:

- Site Investigation
- Landfill
- Sandstone Quarries
- Landslips
- Boreholes

The product is a stand-alone system that provides a directory of geological information, covering specific topics and geographical areas within the Bradford area. 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 in order 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 document provides a brief guide to the program and its operation. Selected examples of the screen formats and user choices are given, a detailed user guide and installation instructions will accompany the disk containing the Bradford database. A more detailed analysis of the program will be provided in a BGS Technical Report.

Upon entering the program the following initial screen is displayed:

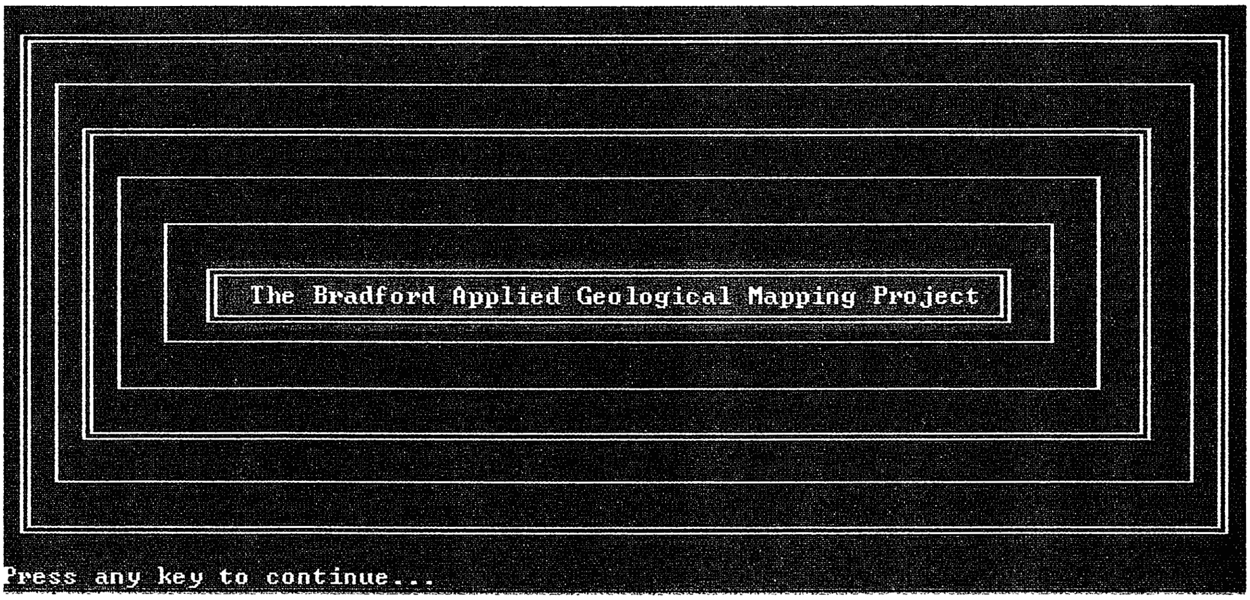


Figure A1 — Initial screen

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.

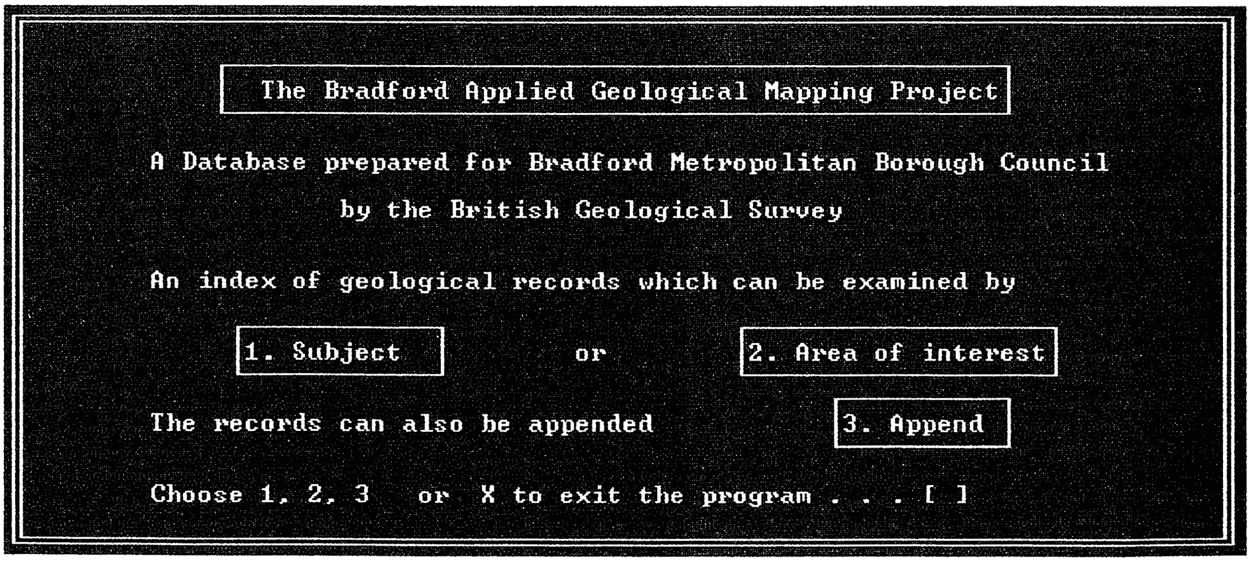


Figure A2 — Main screen

From option **1. Subject** — the following subject screen will appear:

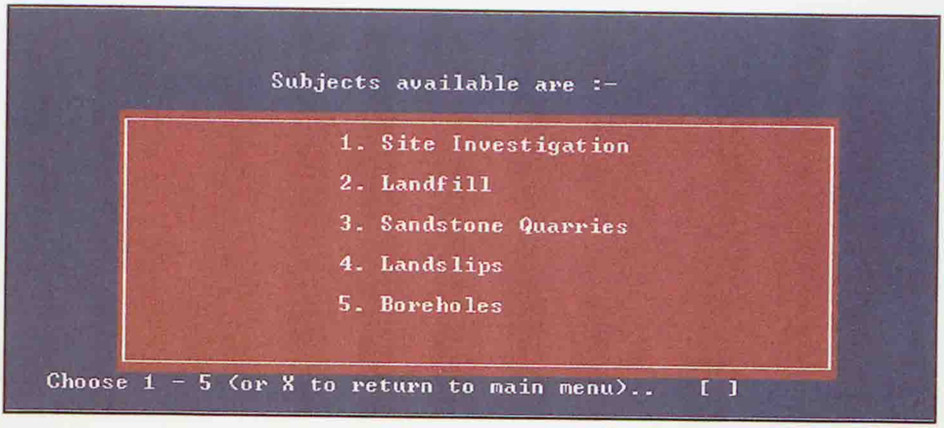


Figure A3 — Subject screen

This gives 5 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 **3. Sandstone Quarries** 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).

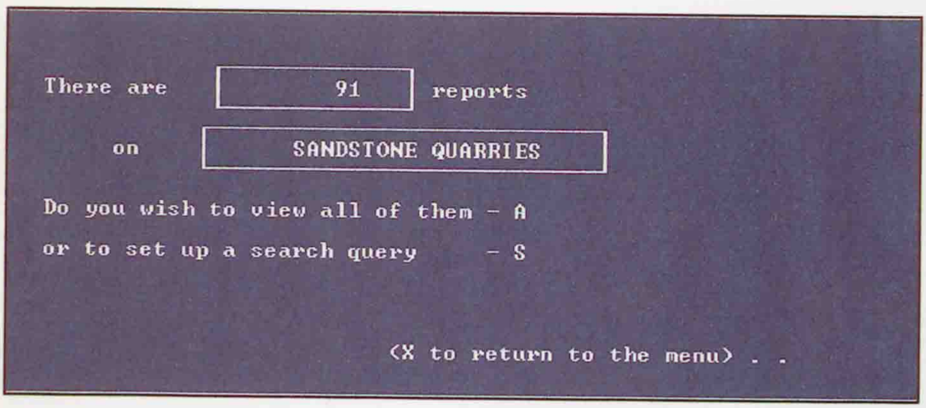
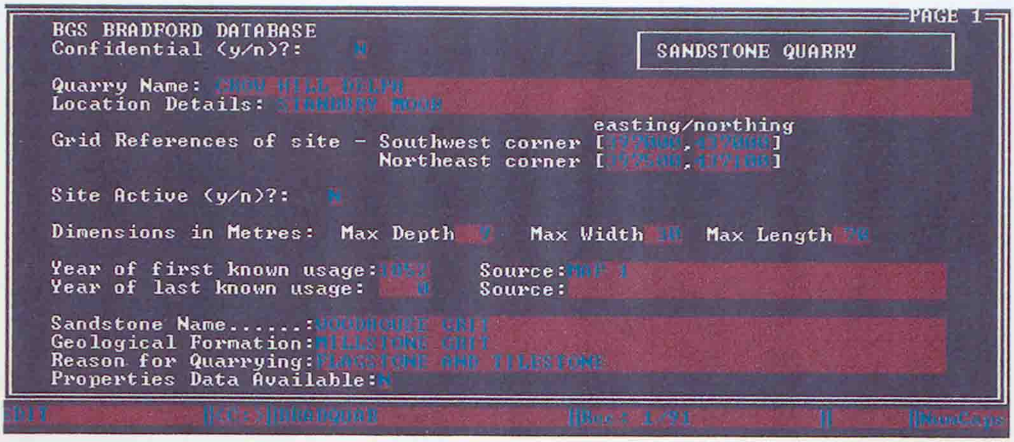


Figure A4 — Result of subject screen

Choosing A (for all) displays the following screen:



Entering <Page Down> will display a second screen:

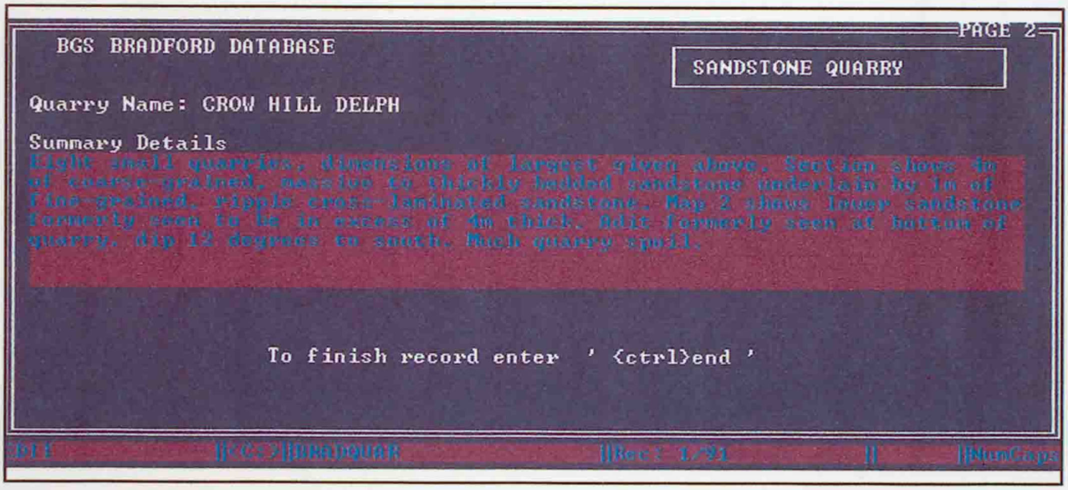


Figure A5 — Sandstone Quarry display screens

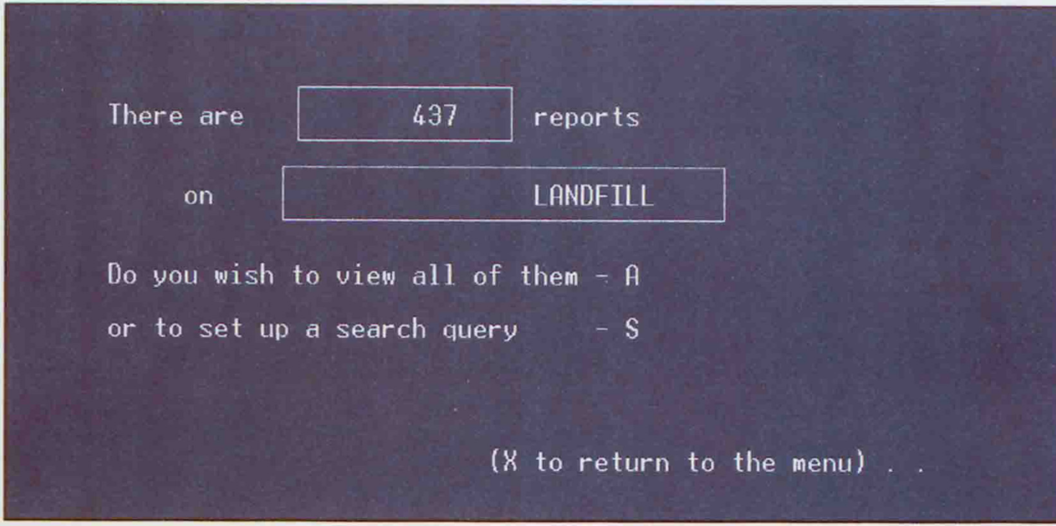


Figure A6 — Landfill selection screen

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.

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

All categories can be scrutinised by searching the database for particular records that contain user-defined data. Selecting **2. Landfill** from the Subject Screen (Figure A3) will lead to the following screen:

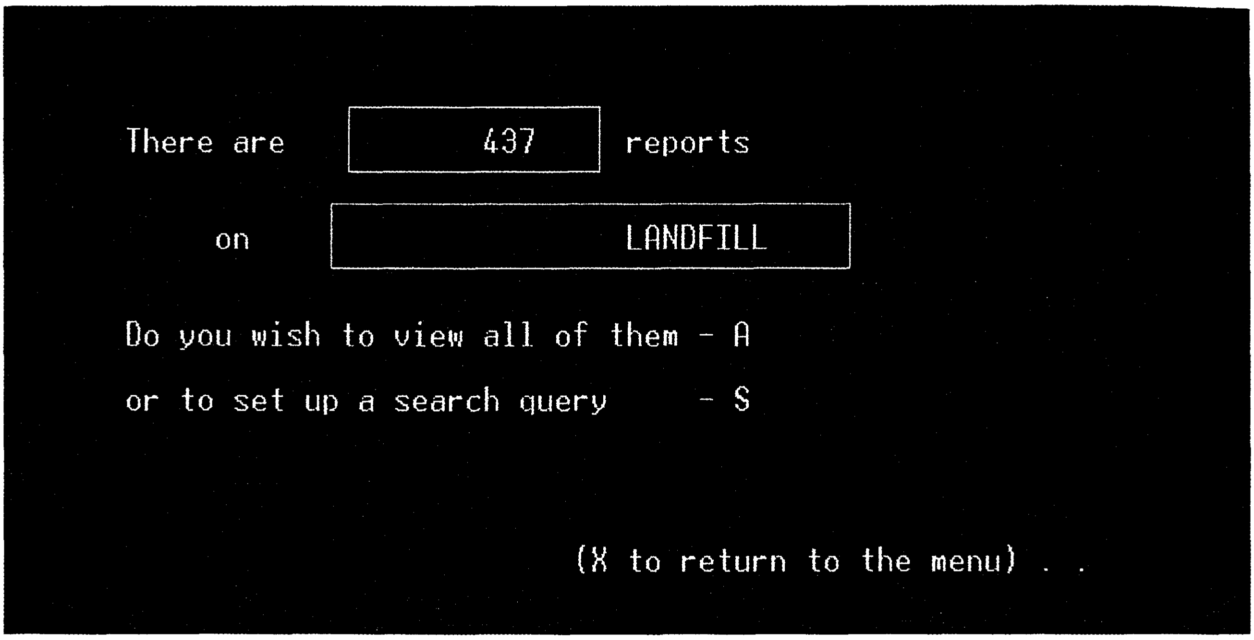
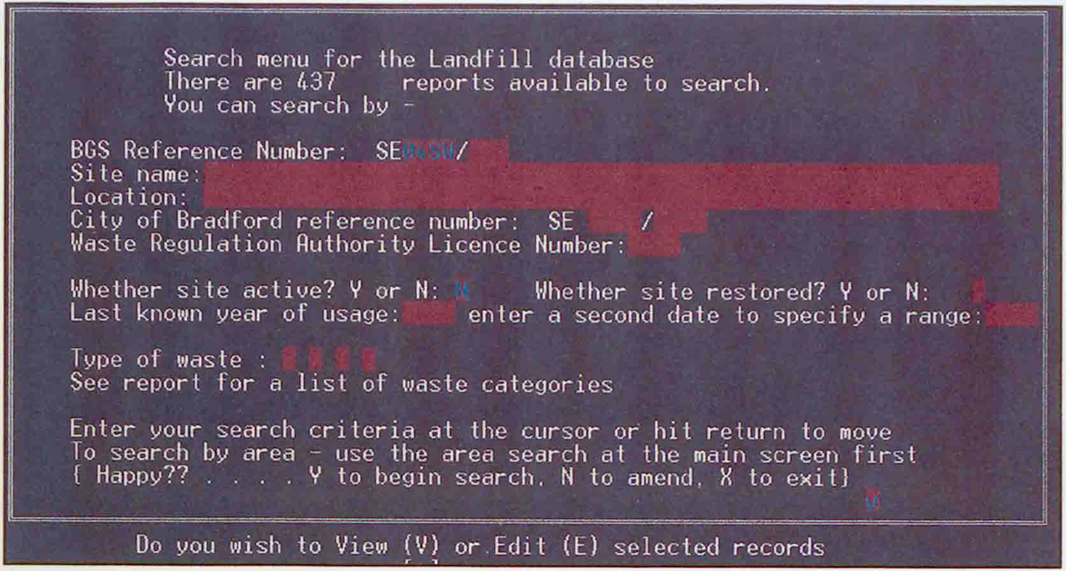


Figure A6 — Landfill selection screen

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.



Search menu for the Landfill database
There are 437 reports available to search.
You can search by -

BGS Reference Number: SE04SW/
Site name:
Location:
City of Bradford reference number: SE /
Waste Regulation Authority Licence Number:

Whether site active? Y or N: N Whether site restored? Y or N:
Last known year of usage: enter a second date to specify a range:

Type of waste :
See report for a list of waste categories

Enter your search criteria at the cursor or hit return to move
To search by area - use the area search at the main screen first
{ Happy?? . . . . . Y to begin search, N to amend, X to exit}
Y

Do you wish to View (V) or Edit (E) selected records

Figure A7 — Landfill selection screen

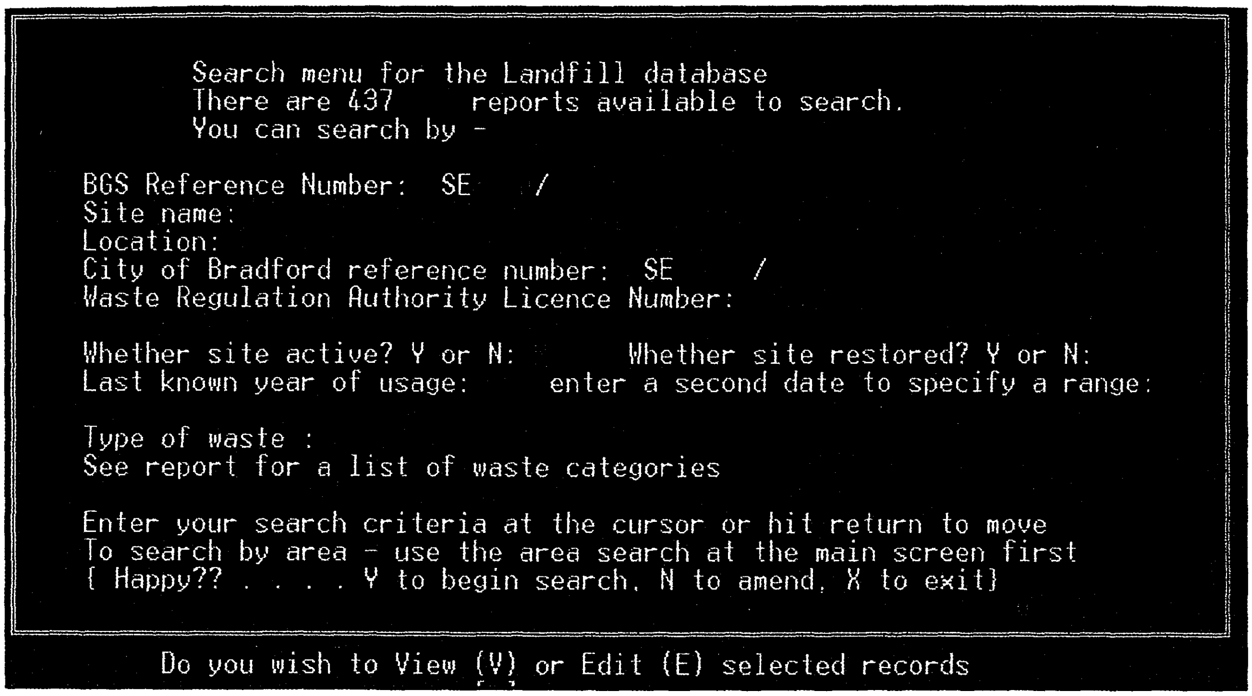
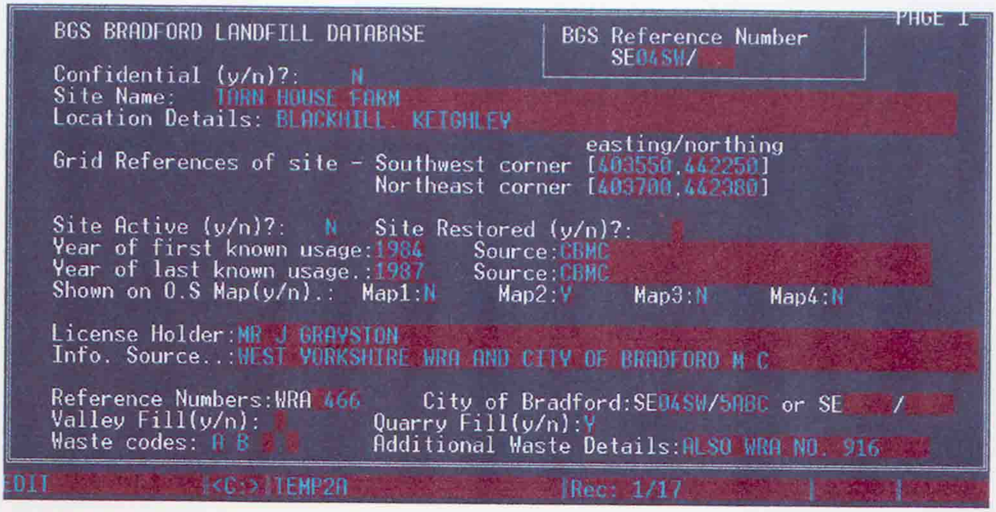


Figure A7 — Landfill selection screen

Once the cursor is positioned over the exit box, the search can begin by giving an affirmative answer ('Y'). Supplying a no ('No') answer will enable you 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 you to enter two dates and hence give a range from which the computer can search.

Once the search has been carried out the records fulfilling the chosen criteria can be displayed on the screen. Selecting V to view will reveal the first record of seventeen selected. The record is displayed as two pages.



PAGE 1

BGS BRADFORD LANDFILL DATABASE

BGS Reference Number
SE04SW/

Confidential (y/n)?: N
Site Name: TARN HOUSE FARM
Location Details: BLACKHILL, KEIGHLEY

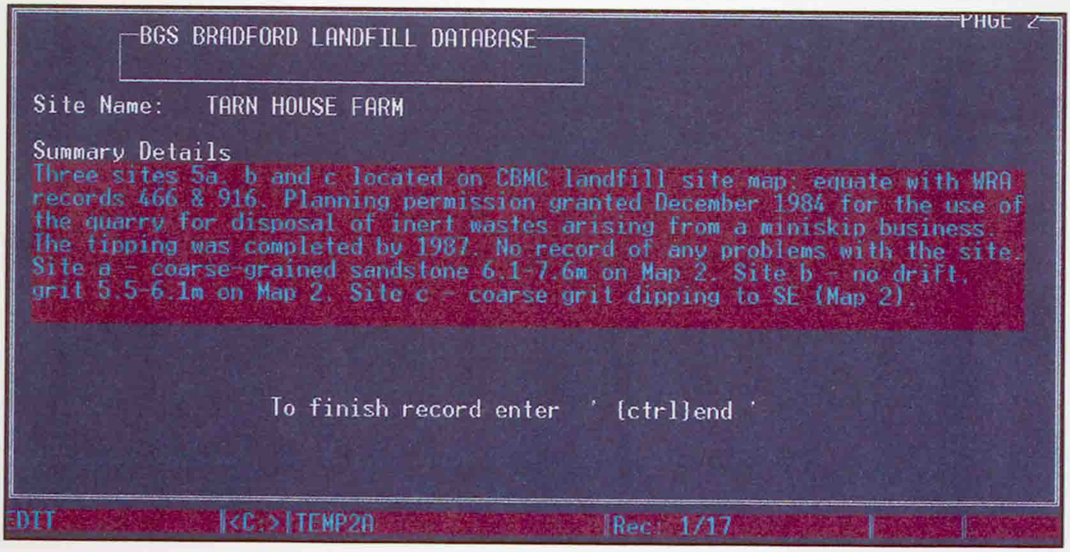
easting/northing
Grid References of site - Southwest corner [403550,442250]
Northeast corner [403700,442380]

Site Active (y/n)?: N Site Restored (y/n)?:
Year of first known usage:1984 Source:CBMC
Year of last known usage.:1987 Source:CBMC
Shown on O.S Map(y/n).: Map1:N Map2:Y Map3:N Map4:N

License Holder:MR J GRAYSTON
Info. Source..:WEST YORKSHIRE WRA AND CITY OF BRADFORD M C

Reference Numbers:WRA 466 City of Bradford:SE04SW/5ABC or SE /
Valley Fill(y/n): Quarry Fill(y/n):Y
Waste codes: A B Additional Waste Details:ALSO WRA NO. 916

EDIT |<C:>|TEMP2A |Rec: 1/17 | |



PAGE 2

BGS BRADFORD LANDFILL DATABASE

Site Name: TARN HOUSE FARM

Summary Details
Three sites 5a, b and c located on CBMC landfill site map; equate with WRA records 466 & 916. Planning permission granted December 1984 for the use of the quarry for disposal of inert wastes arising from a miniskip business. The tipping was completed by 1987. No record of any problems with the site. Site a - coarse-grained sandstone 6.1-7.6m on Map 2. Site b - no drift, grit 5.5-6.1m on Map 2. Site c - coarse grit dipping to SE (Map 2).

To finish record enter ' [ctrl]end '

EDIT |<C:>|TEMP2A |Rec: 1/17 | |

Figure A8 — Landfill display screens

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:

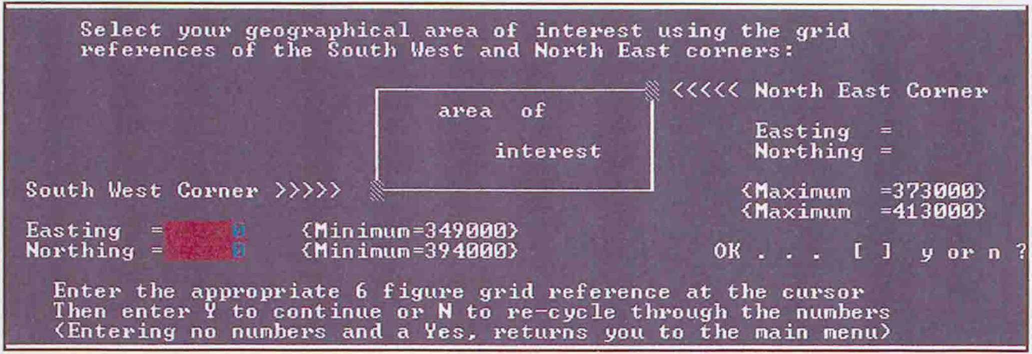


Figure A9 — Area search screen

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:

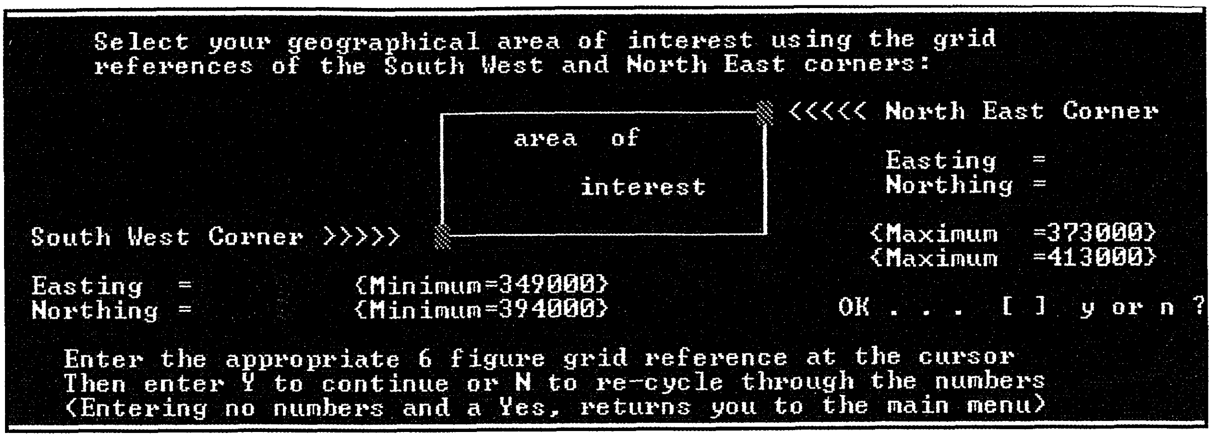


Figure A9 — Area search screen

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 above. Six figure numbers are required and the maximum/minimum values of the Bradford District are given in brackets. The program will not allow nonsensical values, e.g. outside the areas shown or where the NE corner is below the SW corner. Once these have been entered and confirmed with '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.

As a reminder of the chosen area given, 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.

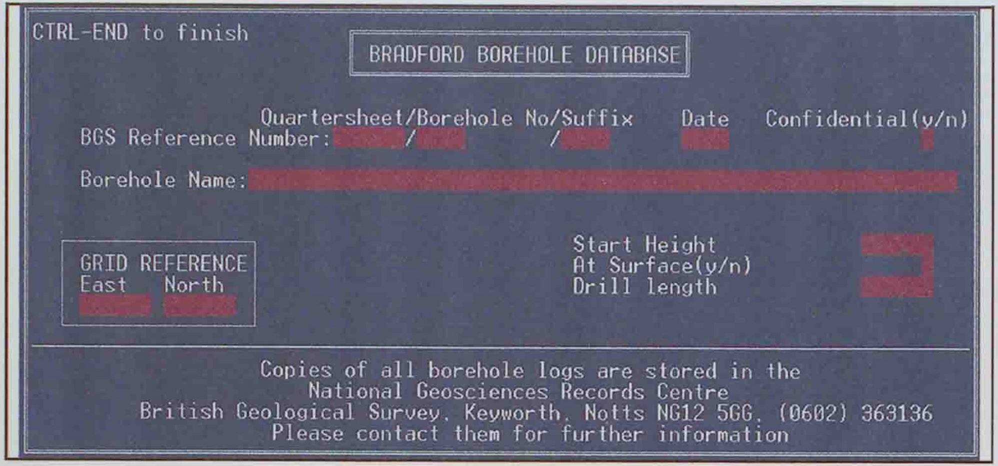


Figure A10 — Borehole entry screen

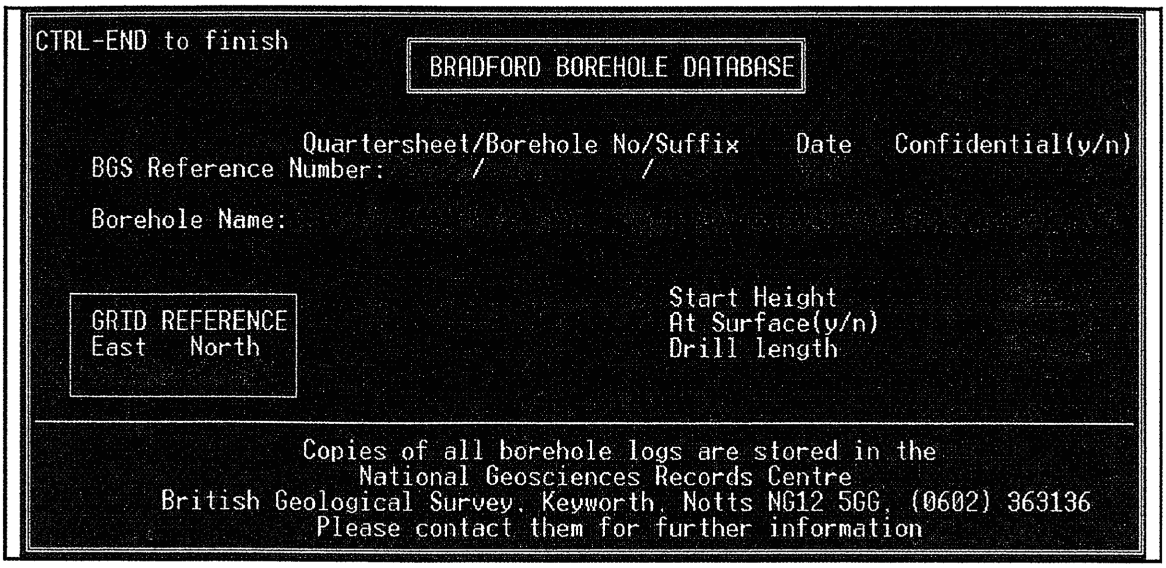


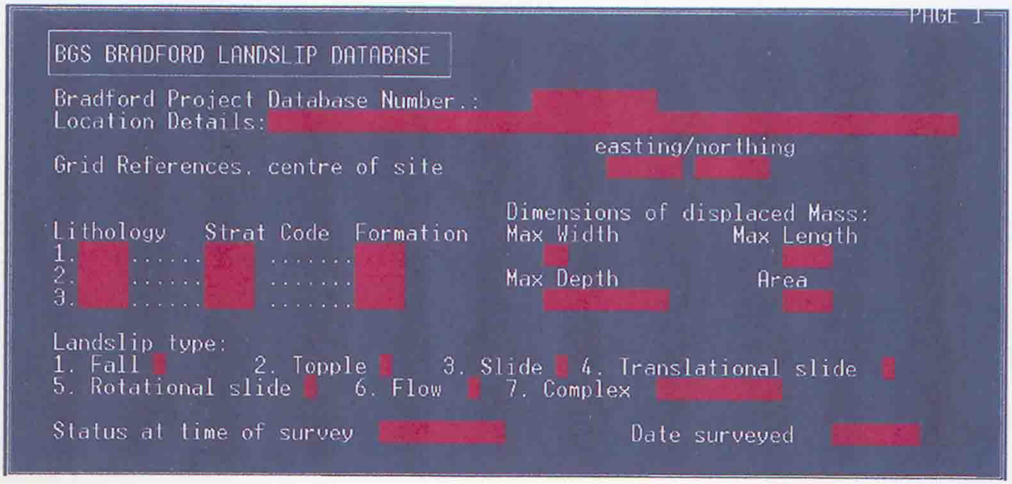
Figure A10 — Borehole entry screen

The third option from the main screen is to append the records. 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 (Figures A10 and A11.

The program allows each of the items to be edited using all of the usual cursor movement functions (e.g. 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.



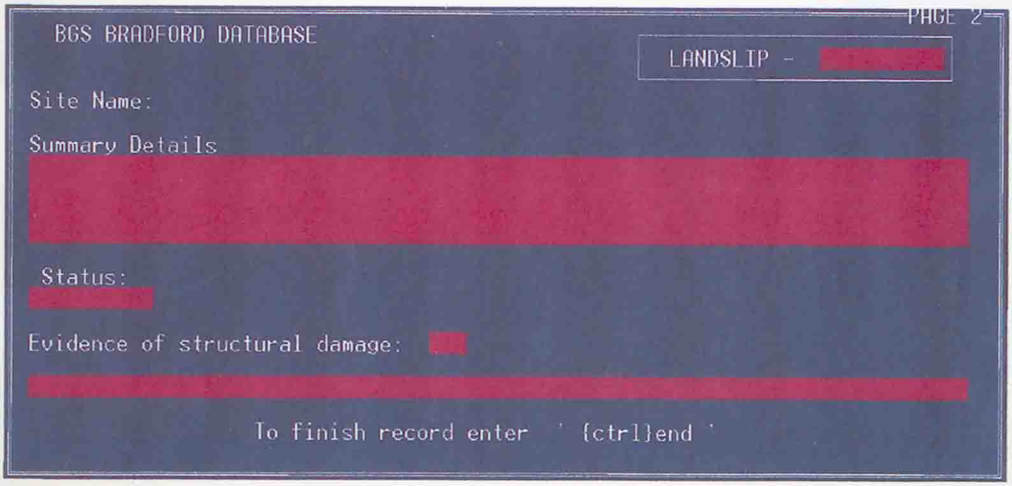


Figure A11 — Entry screens for Landslip records

The final entry screen, that for Site Investigation Reports, is shown on Figure A12.

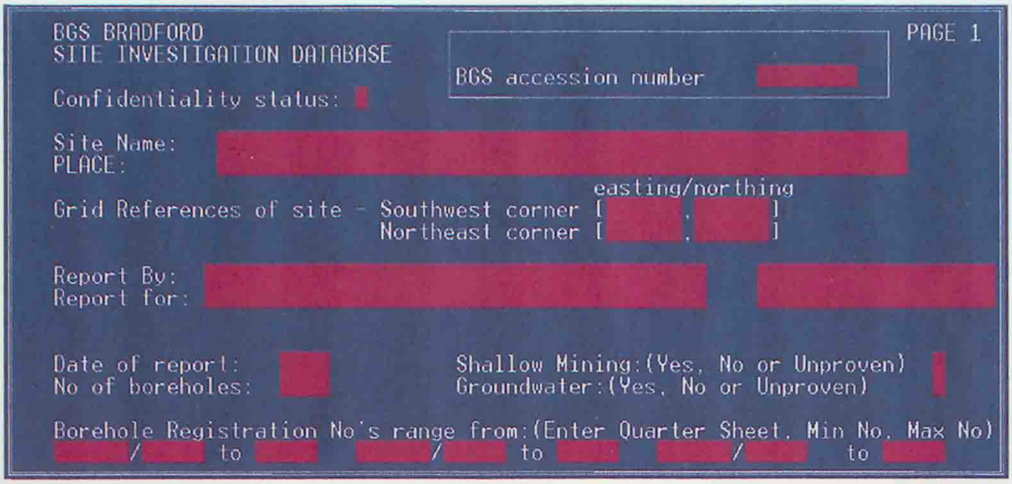


Figure A12 — Entry screen for Site Investigation records

Acknowledgements

The project leader was C N Waters, BGS Thematic Mapping and Onshore Survey Division, under the programme manager T J Charsley, and the direction of the Department of the Environment nominated officer, B R Marker. Planning issues were identified by G Prince and S Bunton, Entec UK Ltd. The engineering geology study was carried out by K Northmore, deputy project leader, a contribution to the information on mineral resources was provided by D E Highley and to hydrogeological information by A Butcher. Development of the computer databases was coordinated by D J D Lawrence and M Stewart. Acid immersion tests were carried out by M A Allen and all other sandstone properties tests by C P M Snee, University of Bradford. The thematic geological maps were produced by C Simpson, using digital methods at BGS Keyworth. Figures were drafted by C Simpson, P Turner and M C Aldiss.

We acknowledge the help provided by the holders of data in permitting the transfer of these records to the National Geosciences Records Centre, BGS Keyworth. We are especially grateful for the assistance provided by members of the local authority, the Coal Authority, Mineral Valuers Office, National Rivers Authority, Yorkshire Water, Waste Regulation Authority, British Rail and numerous civil engineering consultants. The cooperation of landowners, tenants and quarry companies in permitting access to their lands is gratefully appreciated.

In particular, we acknowledge the members of the project Steering Committee for their helpful comments and advice. The Committee comprised the following: D Brook, B R Marker, B Freeland, C Warburton, C Grant, S McGregor, V Forster (DoE); J P Robinson, M Speke (Government Office Yorkshire and Humberside); D Cliff, P Hatherley, W S Caulfield, K Pell, D Fisher, J Dickenson (City of Bradford Metropolitan Council); R M Milner (National House Building Council); J Aldrick (National Rivers Authority); M J Allen, E Watkins (British Coal Corporation); K Pickup (The Coal Authority); J R Wright, D Ramsay (English Nature); E Spivey (Bullen & Partners).

Glossary

ADIT Horizontal or low angle entrance into a mine.

ANAEROBIC Conditions in which oxygen is absent.

ANTICLINE A ridge shaped fold, upward closing.

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 40 cm depth.

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

CLEAT Cleavage in coal.

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 Bradford area are of bituminous rank and range in thickness from coal traces to about 1 metre.

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 sucession 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 Synonym for natural superficial geological deposits

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

FIRECLAY A fossil soil, commonly found in association with coal seams. It may be especially useful as a refractory mineral.

FLANDRIAN The present post-glacial period following the Pleistocene, part of the Quaternary, from 10 000 BP to present.

FLOODPLAIN A tract of land bordering a river, consisting of alluvium deposited by the river.

FLUVIAL Of or pertaining to rivers.

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.

GOAF Waste material from colliery-based mineworkings stored within the workings.

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

GLEY 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.

GROUTING Injection of liquid cement into the ground, where it sets to fill pores and fractures. Used to strengthen rock or impede water flow.

INTERFLUVE Elevated ground between two adjacent valleys.

ISOPACHYTE A contour line joining points of equal thickness of a rock layer or superficial deposit.

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 millimetres thick.

LANDSLIDE Synonym of landslip; a downslope displacement of bedrock or superficial deposits over one or more failure surfaces.

LEACHATE Solution formed when water percolates through a permeable medium. The leachate may be toxic or carry harmful bacteria when derived from some solid wastes.

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

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

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.

MASSIVE Containing no visible internal structures.

MEMBER Subdivisions of a formations each characterised by relatively few and distinctive rock types and associations (e.g. sandstones, marls, coal seams).

MUDSTONE The dominant lithology in the Millstone Grit and Coal Measures, these sedimentary rocks comprise a mixture of sand (>62 μm), silt (4 to 62 μm) and clay (<4 μm)- sized particles. The mudstones usually become increasingly silty upwards and grade into siltstones or pass by intercalation and interlamination with sandy beds into fine-grained sandstone.

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 of an ice sheet influenced by severe cold, where permafrost and freeze thaw conditions are widespread.

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

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

QUATERNARY A sub-era that covers approximately the last 2.0 Ma and includes the Pleistocene and Flandrian epochs.

RECHARGE The downward movement of water from the soil to the water table.

REFRACTORY Resistant to decomposition by heat, pressure or chemical attack.

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

SANDSTONE Sandstones comprise dominantly sand (>62 μm)-sized particles, generally well-cemented and strong with quartz being the dominant clastic component. They commonly form widespread sheets 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.

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 10 cm 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 comprising silt (4 to 62 μm)-sized particles.

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

SUBSIDENCE The settling of the ground or a building in response to physical changes in the subsurface, such as underground mining, clay shrinkage or response to overburden.

SUPERFICIAL DEPOSITS A general term for usually unlithified deposits of Quaternary age, drift, and artificial (man-made) deposits.

SYNCLINE A trough shaped fold, downward closing.

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

TRAFFICABILITY The capacity of a soil to support vehicle movement. This is influenced by soil shear strength and surface friction, ground pressure and vehicle wheel or track configuration.

TRANSMISSIVITY The rate at which groundwater is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

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Simplified map summaries:

Figure 3 from Map 2

Figure 9 from Map 3

Figure 13 from Map 4

Figure 14 from Map 5

Figure 19 from Map 6

Figure 24 from Map 8

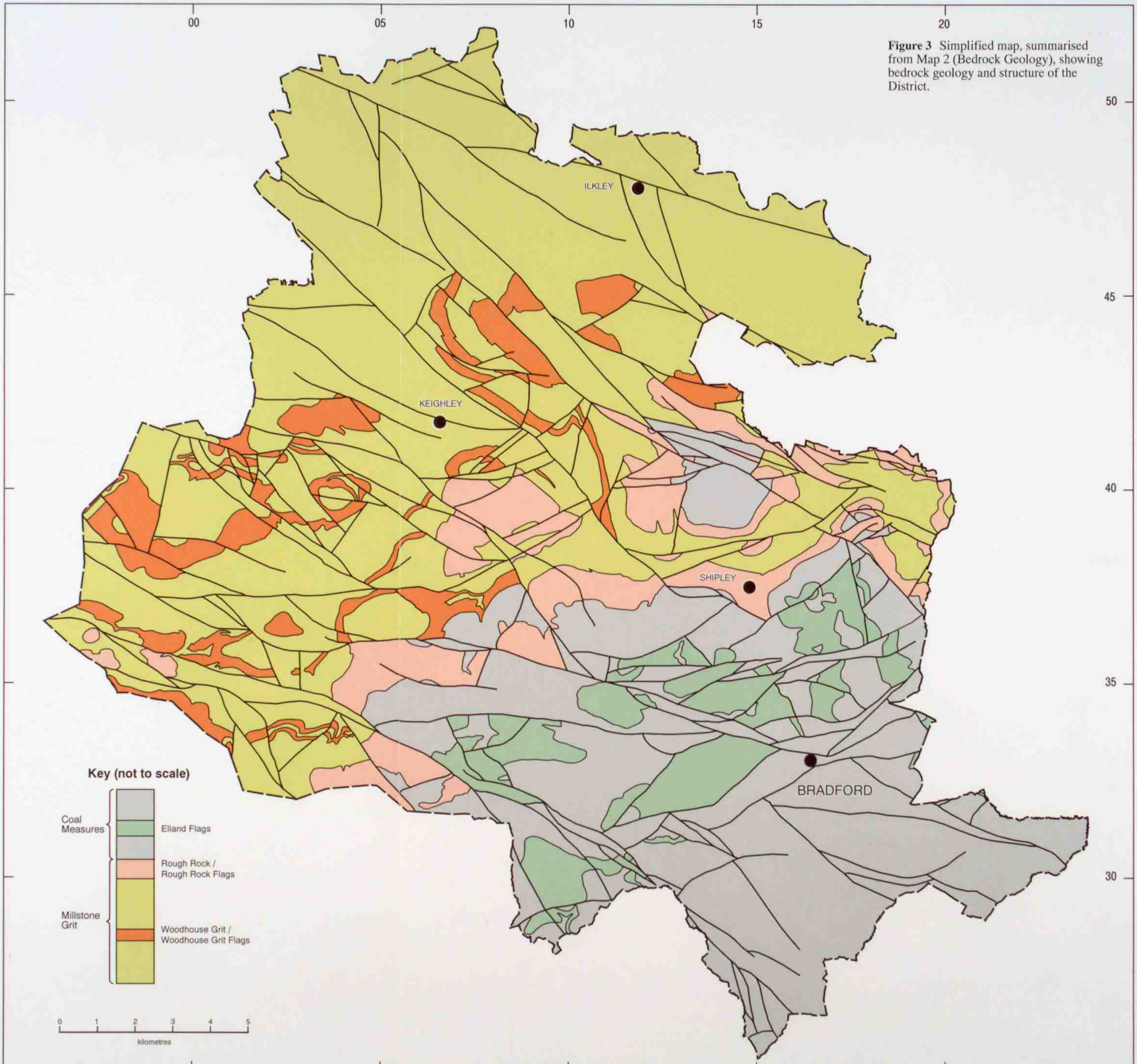

Figure 3 Simplified map, summarised from Map 2 (Bedrock Geology), showing bedrock geology and structure of the District.

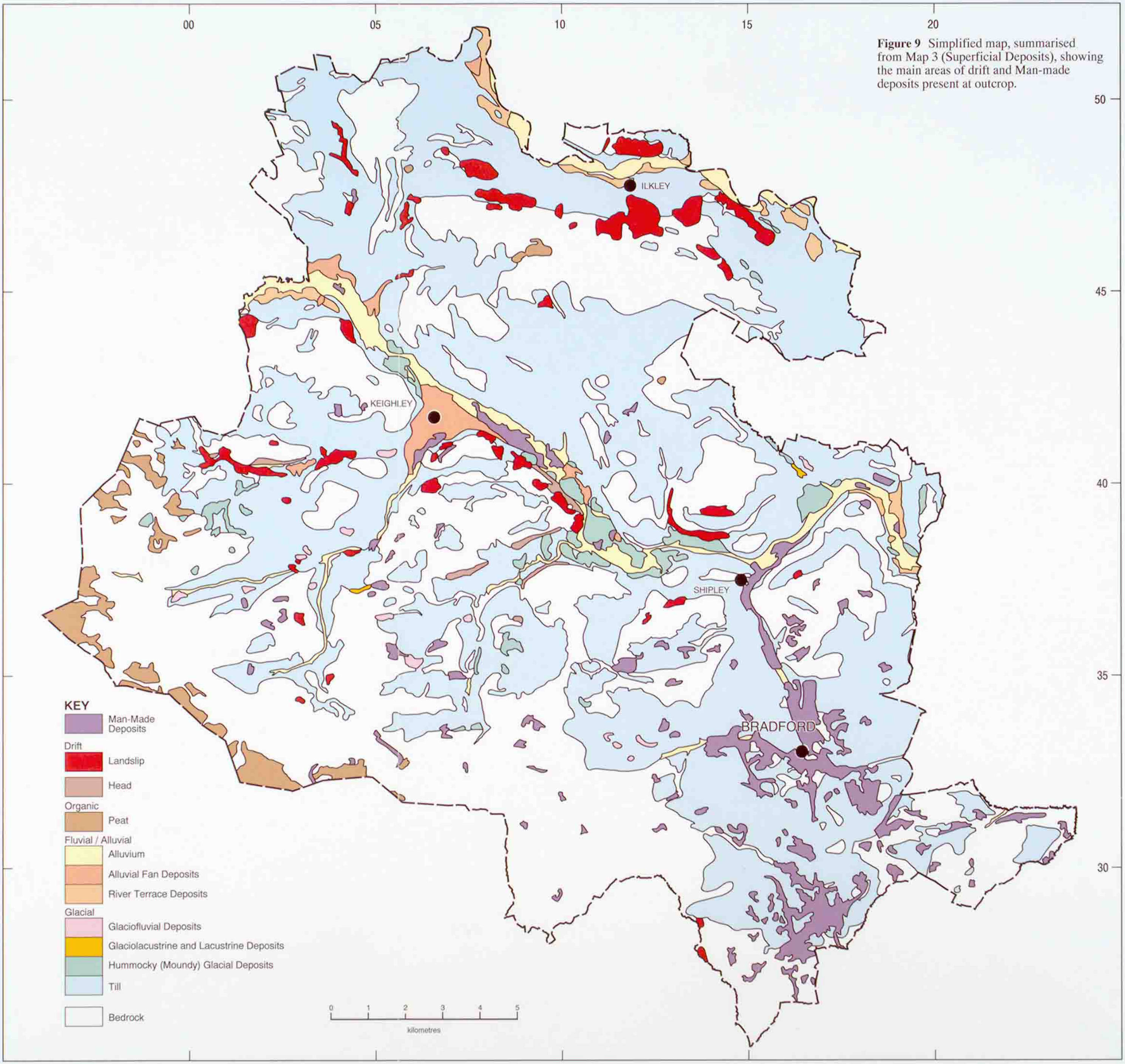

Figure 9 Simplified map, summarised from Map 3 (Superficial Deposits), showing the main areas of drift and Man-made deposits present at outcrop.

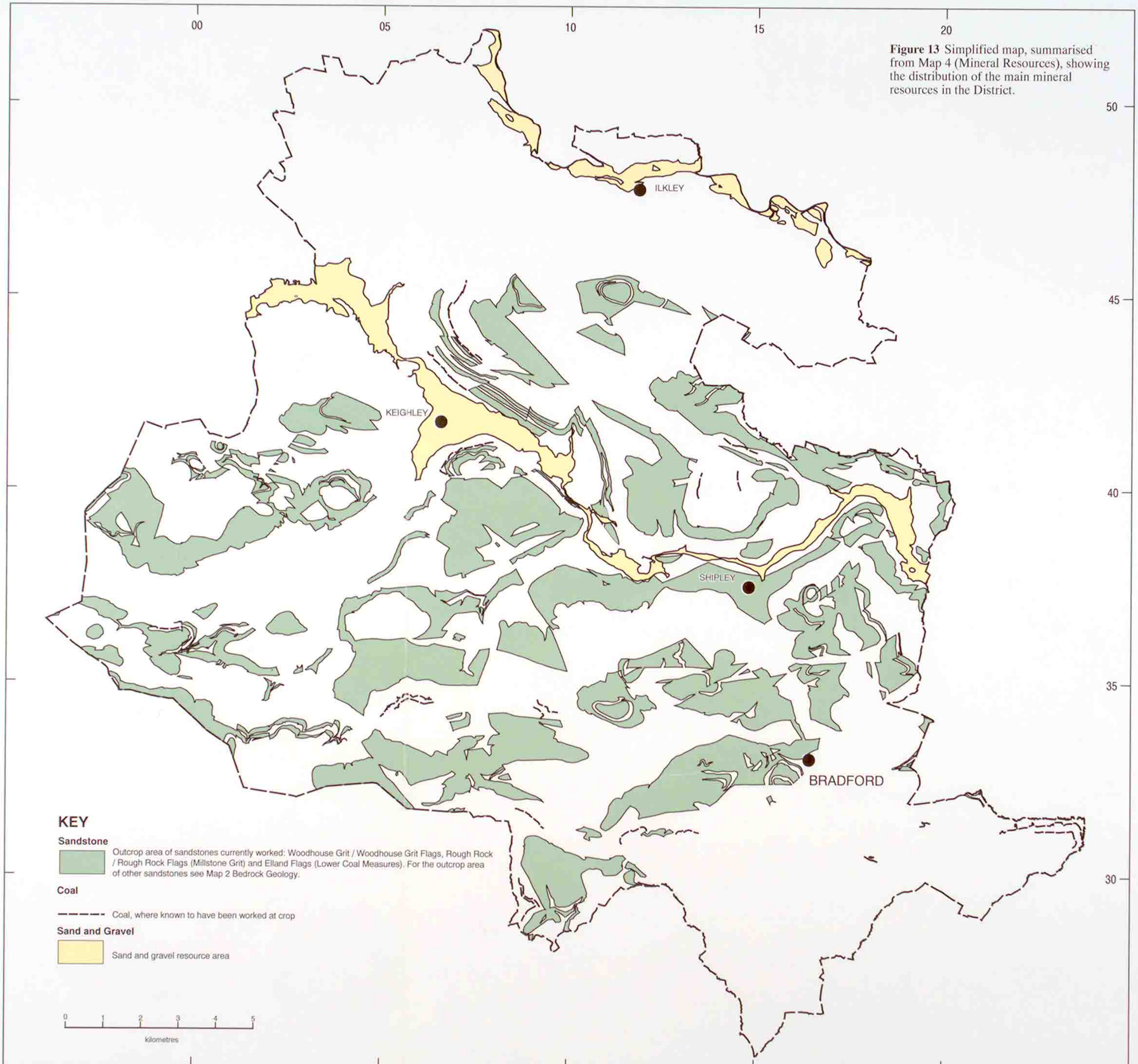

Figure 13 Simplified map, summarised from Map 4 (Mineral Resources), showing the distribution of the main mineral resources in the District.

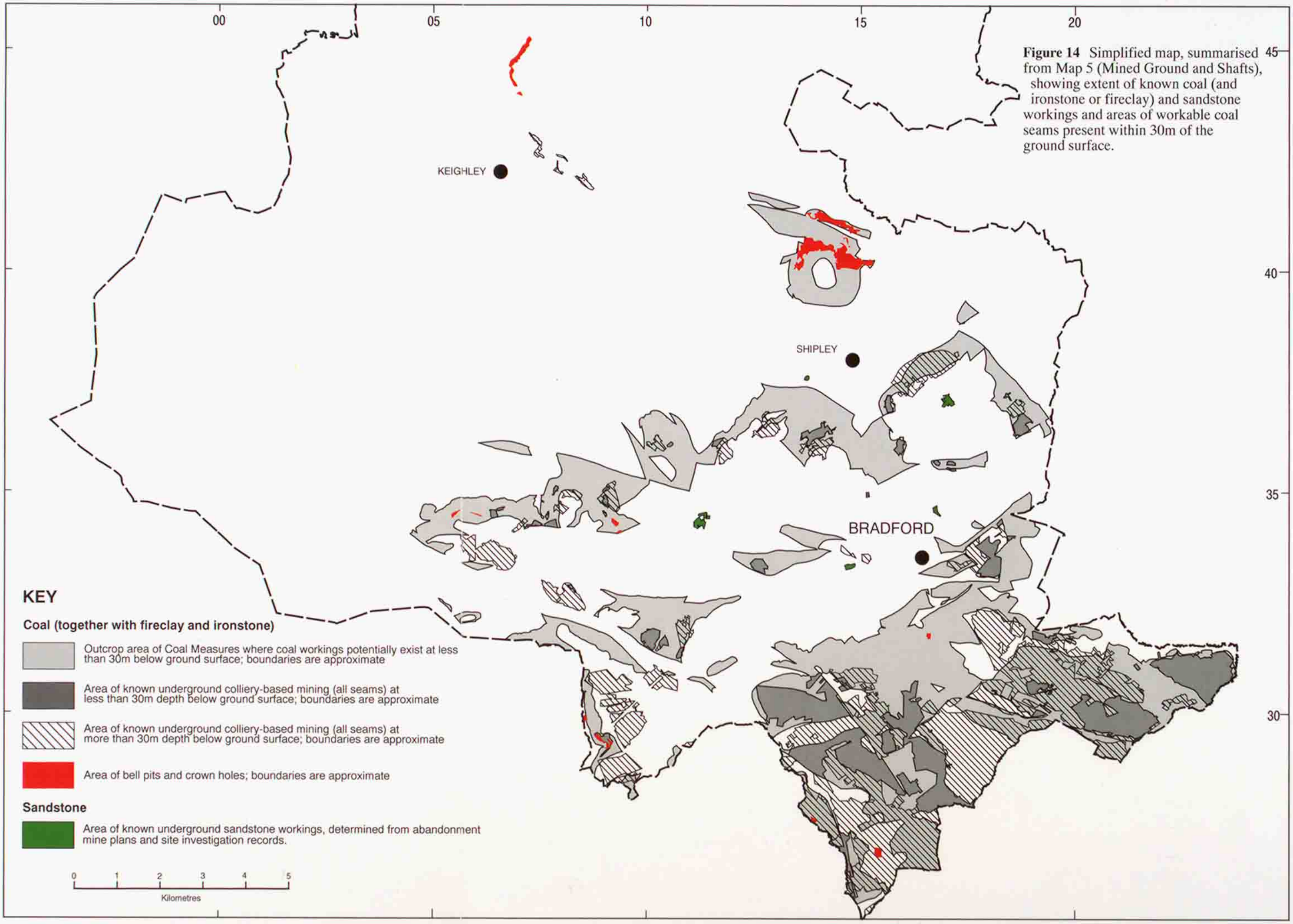

Figure 14 Simplified map, summarised from Map 5 (Mined Ground and Shafts), showing extent of known coal (and ironstone or fireclay) and sandstone workings and areas of workable coal seams present within 30m of the ground surface.

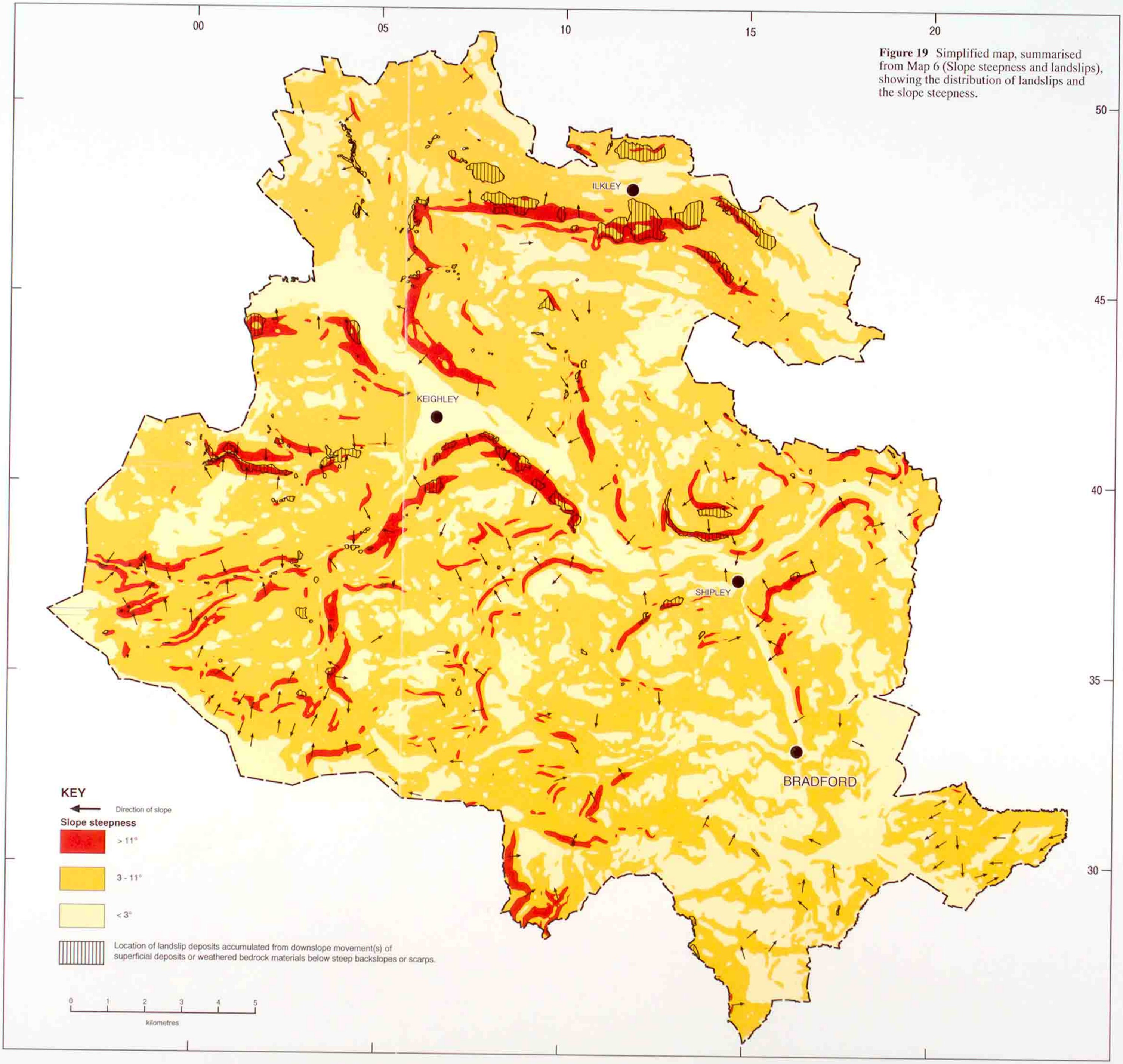

Figure 19 Simplified map, summarised from Map 6 (Slope steepness and landslips), showing the distribution of landslips and the slope steepness.

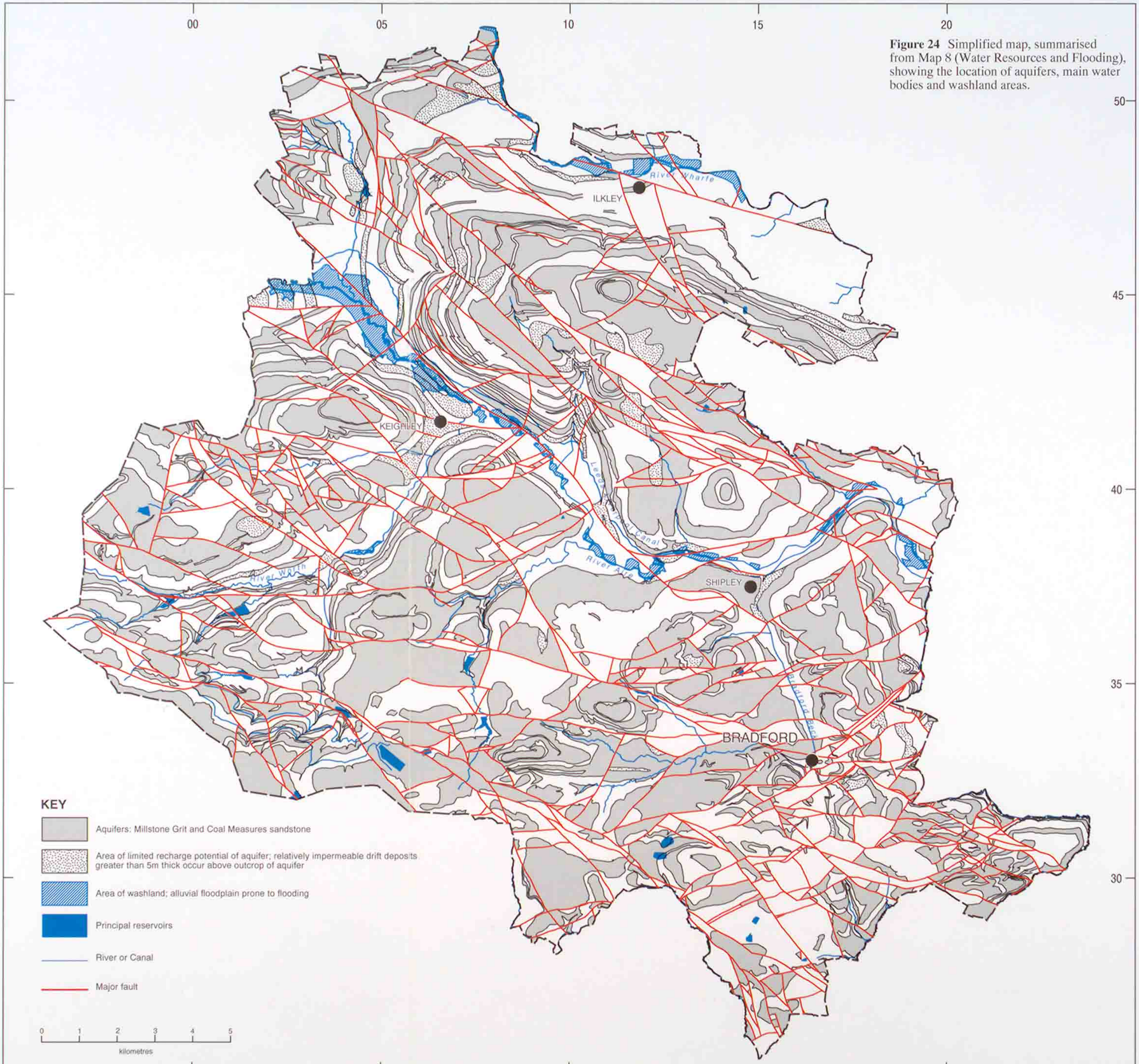

Figure 24 Simplified map, summarised from Map 8 (Water Resources and Flooding), showing the location of aquifers, main water bodies and washland areas.