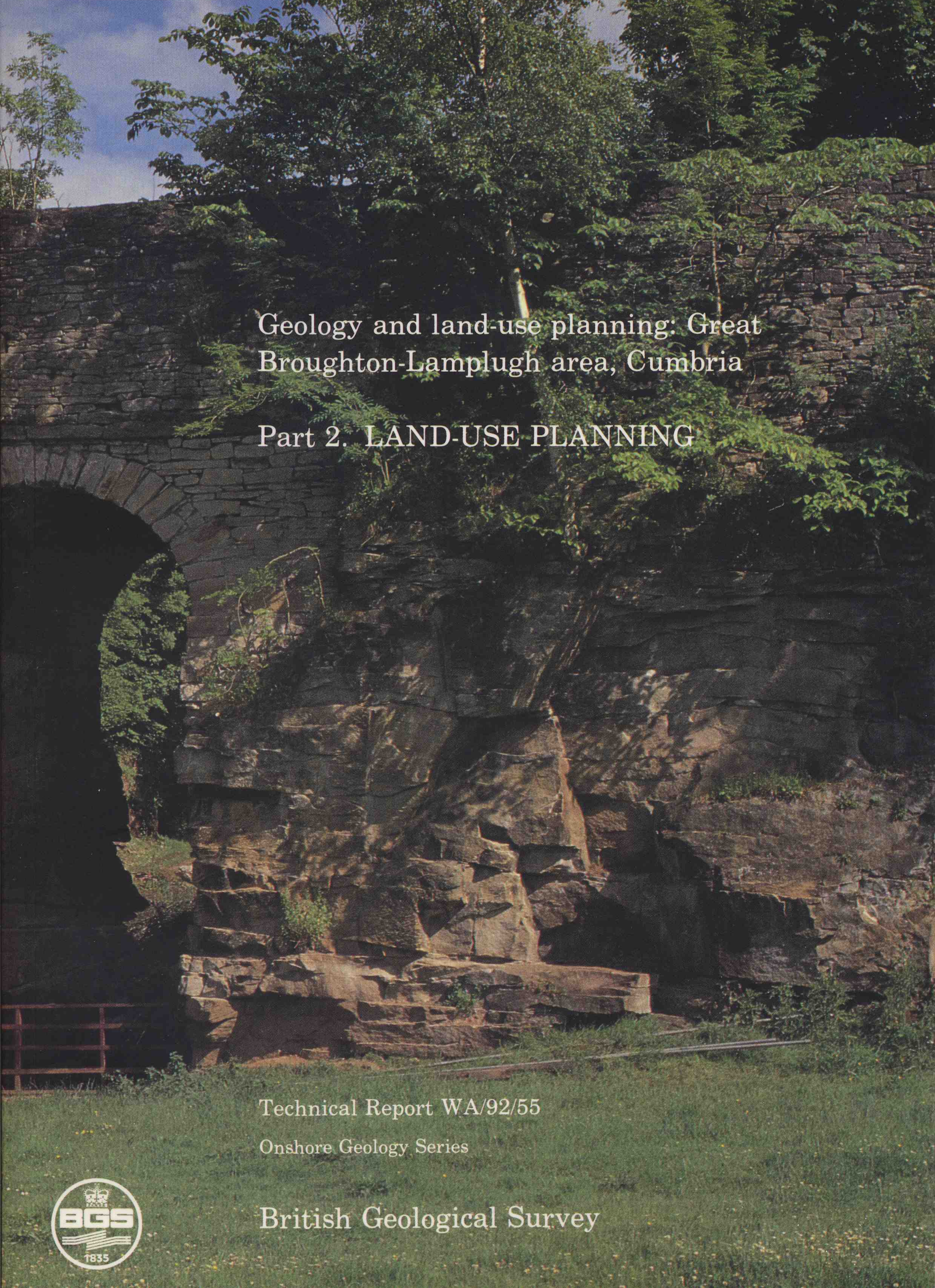


Geology and land-use planning: Great Broughton-Lamplugh area, Cumbria

Part 2. LAND-USE PLANNING

Technical Report WA/92/55

Onshore Geology Series

British Geological Survey

BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/92/55
Onshore Geology Series

Geology and land-use planning: Great Broughton-Lamplugh area, Cumbria

Part 2. LAND-USE PLANNING

M P Boland and B Young

Contributor
R A Monkhouse

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

Bibliographic reference
Boland, M P, and Young, B. 1992. Geology and land-use planning: Great Broughton-Lamplugh area, Cumbria. Part 2. LAND-USE PLANNING. *British Geological Survey Technical Report* WA/92/55.

Keyworth, Nottingham British Geological Survey 1992

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and at Murchison House, Edinburgh, and in the BGS London Information Office in the Natural History Museum Earth Galleries. The adjacent bookshop stocks the more popular books for sale over the counter. Most BGS books and reports are listed in HMSO's Sectional List 45, and can be bought from HMSO and through HMSO agents and retailers. Maps are listed in the BGS Map Catalogue, and can be bought from Ordnance Survey agents as well as from BGS.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG
☎ Nottingham (0602) 363100 Telex 378173 BGSKEY G
Fax 0602–363200

Murchison House, West Mains Road, Edinburgh EH9 3LA
☎ 031–667 1000 Telex 727343 SEISED G
Fax 031–668 2683

London Information Office at the Natural History Museum Earth Galleries, Exhibition Road, South Kensington, London SW7 2DE
☎ 071–589 4090 Fax 071–584 8270
☎ 071–938 9056/57

19 Grange Terrace, Edinburgh EH9 2LF
☎ 031–667 1000 Telex 727343 SEISED G

St Just, 30 Pennsylvania Road, Exeter EX4 6BX
☎ Exeter (0392) 78312 Fax 0392–437505

Bryn Eithyn Hall, Llanfarian, Aberystwyth, Dyfed SY23 4BY
☎ Aberystwyth (0970) 611038 Fax 0970–624822

Windsor Court, Windsor Terrace, Newcastle upon Tyne NE2 4HB
☎ 091–281 7088 Fax 091–281 9016

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS
☎ Belfast (0232) 666595 Fax 0232–662835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ Wallingford (0491) 38800 Telex 849365 HYDROL G
Fax 0491–25338

Parent Body

Natural Environment Research Council

Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU
☎ Swindon (0793) 411500 Telex 444293 ENVRE G
Fax 0793–411501

Printed in England for the British Geological Survey by Derry and Sons Limited, Nottingham

CONTENTS

FIGURES

TABLES

PREFACE

This report is one of two which presents the results of a survey of the geology of the Great Broughton-Lamplugh area of Cumbria. This volume, Part 2, reviews the geological factors relevant to land-use planing and development. A separate volume, Part 1, describes the geology in detail.

The district is covered by 1:10 000 sheets NY 03 SE, NY 02 NE and SE and lies within 1:50 000 geological sheets 22 (Maryport) and 28 (Whitehaven). The district was first surveyed at the six-inch scale by T V Holmes, R Russell and J C Ward and published in 1892 on the one-inch scale as Old Series Quarter Sheets 101 NW and 101 SW. Some revision of these sheets was undertaken in 1894 by J G Goodchild and Sir A Strahan with assistance by J D Kendall, and new editions were published in 1895. A detailed resurvey of the area was carried out between 1921 and 1927 by T Eastwood and E E L Dixon as part of the full revision of one-inch sheets 28 and 22. The new maps were published in 1929 and 1930 respectively as separate solid and drift editions: sheet memoirs were issued in 1931 and 1930.

The present survey, which was jointly funded by the Department of Environment and the British Geological Survey, revised the geological maps and prepared thematic maps designed for use by planners and developers. It was undertaken between 1989 and 1990 by M P Boland (NY 03 SE, NY 02 SE (part)) and B Young (NY 02 NE, NY 02 SE (part)).

Palaeontological work was undertaken by P J Brand: R A Monkhouse compiled the section on hydrogeology, K Ball offered useful advice on radon and R Musson provided information on seismicity. Advice and assistance with establishing the computerised database was given by D J D Lawrence and B Porteous. The maps were drawn by Mrs C Simpson under the supervision of R Parnaby in the Keyworth Drawing office of BGS.

The programme managers were D J Fettes (BGS) and S H Mallett and S Cosgrove (DOE).

We are grateful for much help and valuable information provided by British Coal, both the Opencast Executive and deep mines North-western area, Tendley Hill Quarries Ltd, Cumbria County Council and numerous land owners.

Mrs J Dunkley and Mrs S Clothier are thanked for preparing the typescript.

P J Cook, DSc

Director
British Geological Survey
Keyworth
Nottingham NG12 5GG

EXPLANATORY NOTES

This report is one of two which describes the results of a research project funded jointly by the Department of the Environment and the British Geological Survey. The objectives of the project were to provide an up-to-date geological database for the Great Broughton-Lamplugh area as a foundation for land use and development, effective future geological research and the safeguarding of mineral resources. Part 1 (BGS Technical Report WA/92/54), available separately, describes the geology. The results, with particular emphasis on land-use planning, are described here. The present study is the third DOE sponsored applied geological mapping project in Cumbria; previous surveys have covered the Workington and Maryport, and Dearham and Gilcrux areas.

The British Geological Survey has undertaken these studies as part of the programme to maintain its coverage of 1:10 000 scale geological maps of the UK.

Several centuries of coal mining and, in recent decades, an extensive search for coal seams which could be worked opencast, have provided a wealth of geological data for the district. In compiling this report and accompanying maps, data from the following sources were collated and interpreted:

- a detailed geological field survey at 1:10 000
- deep mine coal boreholes and shaft records
- deep mine coal abandonment plans
- opencast coal prospecting boreholes
- opencast coal completion plans
- site investigation boreholes, trial pits and reports
- existing geological maps
- Local Authority data
- geological reports and journals.

The type, quantity, quality and limitations of each of these data sources are discussed.

Computerised databases of borehole and geotechnical information comprising more than 16 000 records (i.e. lines of data) were established. Their structure and value, both current and potential, are described in Appendices A and B of this report. Computer-aided and conventional techniques were used to produce the 1:10 000 scale standard geological maps, the 1:25 000 scale thematic maps and the accompanying reports.

All National Grid references in this report lie within the 100 km square NY. Grid references are given to either eight figures (accurate to within 10 m), or six figures for more extensive locations.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. NY 03 SE/1). The first two elements define the 10 km square of the National Grid in which the borehole is situated (e.g. NY 03); the third element defines the quadrant of that square (e.g. SE), and the fourth is the accession number of that borehole. In the text of the report the borehole/shaft is normally referred to by the last three elements alone (e.g. 03 SE/1).

The word 'district', unqualified, in this account means the whole ground covered by NY 03 SE, NY 02 NE and SE.

The maps were constructed in February 1991. No information subsequent to that date has been taken into account.

LIMITATIONS

This report and accompanying maps have been produced by the collation and interpretation of data from a wide variety of sources. However, the data are not comprehensive and do vary in quality. It is inevitable that this will be reflected in the documents presented; local features and conditions may not be represented and many boundaries may be approximate.

CONFIDENTIALITY

Confidential data, chiefly British Coal Opencast Executive prospecting information, have been taken into account and used in a generalised way during the preparation of the geological maps and this report, but details of specific boreholes are not individually quoted.

Data used in preparing this report and associated maps are lodged at the Newcastle upon Tyne office of the British Geological Survey. (Windsor Court, Windsor Terrace, Newcastle upon Tyne, NE2 4HB, Tel: 091-281 7088; Fax: 091-281 9016.) Any enquiries concerning these documents should be directed to that office.

The following reports describe the adjoining areas:

BARNES, R P, YOUNG, B, FROST, D V, and LAND, D H. 1988. Geology of Workington and Maryport. *British Geological Survey Technical Report* No. WA/88/3.

YOUNG, B, and ARMSTRONG, M. 1989. The applied geological mapping of the Dearham and Gilcrux area, Cumbria. *British Geological Survey Technical Report* No. WA/89/70.

NOTES

Data used in preparing this report and associated maps are lodged at the Newcastle upon Tyne office of the British Geological Survey (Windsor Court, Windsor Terrace, Newcastle upon Tyne NE2 4HB; tel: 091 281 7088; fax: 091 281 9016. Any enquiries concerning these documents should be directed to that office.

The following reports describe the adjoining areas:

Barnes, R P, Young, B, Frost, D V and Land, D H. 1988. Geology of Workington and Maryport. *British Geological Survey Technical Report,* No. WA/88/3.

Young, B, and Armstrong, M. 1989. The applied geological mapping of the Dearham and Gilcrux area, Cumbria. *British Geological Survey Technical Report,* No. WA/89/70.

All National Grid references in this report lie within the 100 km square NY. Grid references are given to either eight figures (accurate to within 10 m), or six figures for extensive locations.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. NY 03 SE/8). The first elements define the 10 km square (of the National Grid) in which the borehole is situated; the third element defines the quadrant of that square, and the fourth is the accession number of that borehole. In the text of the report the borehole/shaft is normally referred to by the last three elements alone (e.g. 03 SE/8).

The word ‘district’, unqualified, in this account means the whole ground covered by the report.

EXECUTIVE SUMMARY: LAND USE PLANNING

Introduction

The Great Broughton-Lamplugh district includes part of the Cumbrian coalfield and the northernmost part of the West Cumbrian iron orefield. The east of the district is underlain predominantly by limestones whereas the low fells in the south-east of the district are formed by resistant, older siltstones and sandstones which form part of the Lake District. Exploitation of these rocks, together with the effects of natural geological processes, has resulted in variable ground conditions throughout the area. Coal mining has left a legacy of spoil heaps, underground workings and abandoned shafts. Areas of variably restored opencast coal workings, clay pits and quarries for sandstone, limestone and siltstone also occur. Resources of coal, limestone, sandstone and sand and gravel remain in the district. Natural phenomena such as limestone dissolution may also lead to ground collapse. Thus the availability of comprehensive, up-to-date information on the geological environment is essential for planners, geologists and engineers when considering both issues relating to ground stability and future resource development within the area.

Two sets of maps and accompanying reports have been prepared.

1. Geology report WA/92/54 with text detailing the solid and drift geology of the area:
Three geological maps at 1 10 000 scale.

2. Land-use planning report WA/92/55:
A series of nine thematic maps at the 1:25 000 scale with accompanying text detailing geological factors for consideration in land use planning.

The study was jointly funded by the Department of Environment and the British Geological Survey (BGS). The work was carried out by BGS staff at the Newcastle upon Tyne office. Hydrogeological information was supplied by BGS Wallingford.

Objectives

1) To produce new geological maps of the area incorporating all available geological information.

2) To collect and organise borehole and mine-plan data into a database/archive.

3) To identify elements of the geology which are of particular interest to planners and developers and to present this information in a form that is understandable to those not trained in geology or related disciplines.

4) To highlight the limitations of interpretations based on the existing data-set and to indicate the need for further specialist advice in relation to specific planning proposals or objectives.

Methodology

The work involved the collation and interpretation of data from many different sources; a specially commissioned 1:10 000 scale field geological survey together with examination of coal exploration boreholes, deep mine and opencast coal abandonment plans, site investigation boreholes and reports, existing geological maps and memoirs and other archival material held by third parties. Computerised databases of borehole and geotechnical information were established.

Conclusions

The study has produced a comprehensive re-interpretation of the geology of the district. The new 1:10 000 geological maps, 1:25 000 thematic maps, reports and databases provide a thorough framework for the evaluation of geological issues in land-use planning and planning decisions. The principal geological factors highlighted by this work are:

1. Areas of shallow coal mining exist which may cause stability problems. Many shafts and adits have been identified within the area, though undoubtedly others exist.

2. Large, underground voids related to iron ore working exist. The behaviour of these voids is difficult to predict.

3. Made ground and fill is extensive. The variable nature of these deposits makes prediction of related problems difficult. Backfilled opencast workings, quarries and former colliery sites have been identified. However, smaller quarries and pits undoubtedly exist and may cause localised instability.

4. Gas production, either within old coal workings, natural limestone cavities or from waste within backfill sites may prove hazardous.

5. Dissolution of limestone may result in surface instability. This phenomenon occurs on the limestone outcrop and where the limestone is overlain by mudstones, siltstones and sandstones of the Hensingham Group.

6. Slopes may prove unstable where these are stepened or undercut by natural erosion or by excavation, or are overpressured when materials are deposited or structures built on them.

7. Resources of coal, limestone, and sand and gravel exist within the district. These should be taken into account in forward-planning of land use. Resources of other minerals such as sandstone also

occur but are unlikely to be of economic significance.

This study has attempted to collate and evaluate all relevant geological data. However the maps and reports produced should not be seen as an alternative to a detailed site investigation when planning a development project. The reader is strongly advised always to consult primary sources of data. Where mining is suspected the mine plans and shaft atlases maintained by British Coal and the abandonment plans of non-coal mines held by the Health and Safety Executive should be consulted.

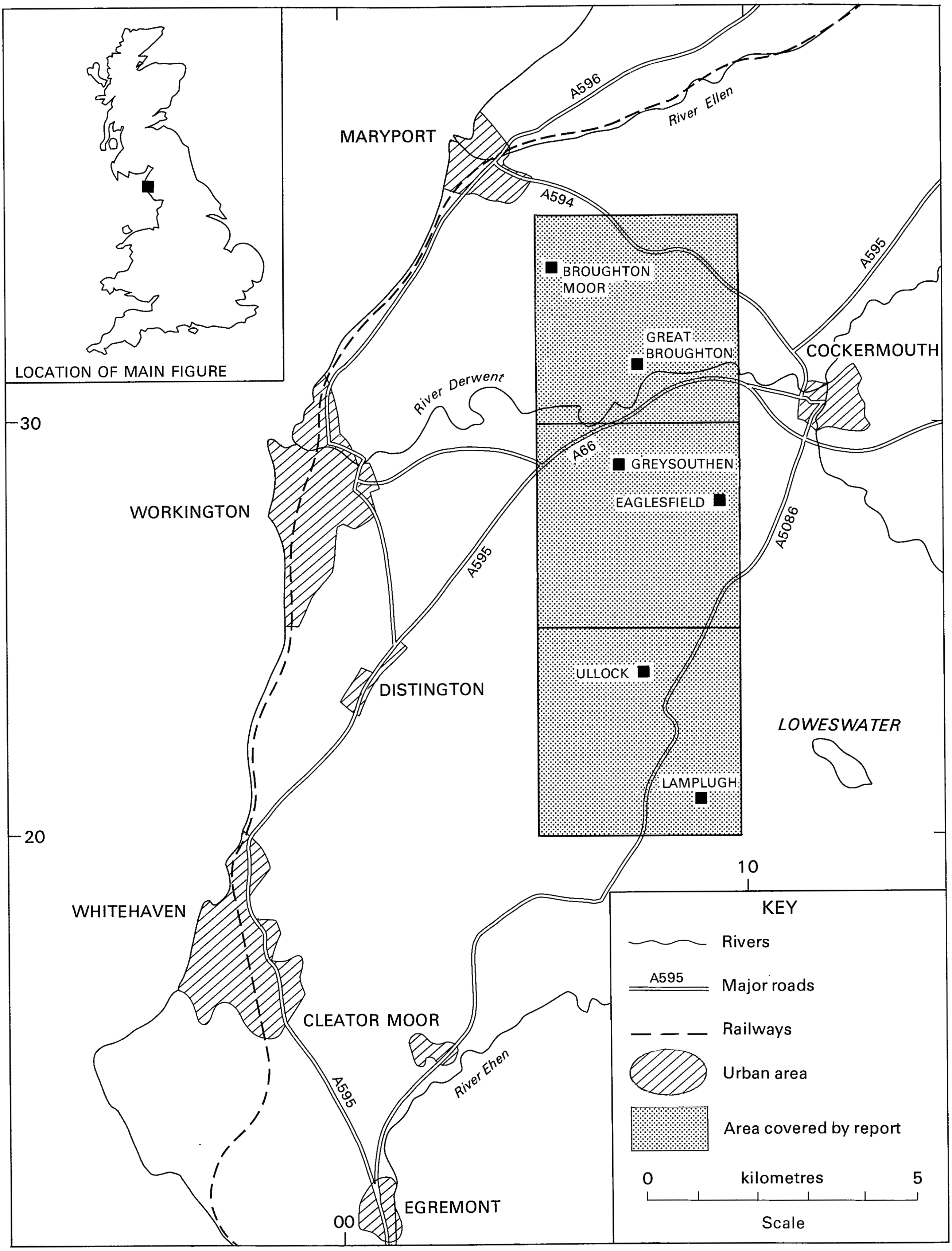


Figure 1 Location map

1 INTRODUCTION

1.1 Geographical setting

Described in this report is a belt of country of some 75 km^2 lying immediately to the west and south-west of Cockermouth within the Allerdale and Copeland districts of Cumbria (Figure 1). This is a predominantly rural area with population concentrated mainly in the comparatively large villages of Broughton Moor, Great Broughton and Brigham in the north and in the smaller settlements of Eaglesfield, Dean, Branthwaite, Ullock and Lamplugh further south. Scattered farms occur between the villages.

A varied landscape reflects the diversity of the underlying geology. The area includes parts of the eastern margin of the Cumbrian Coalfield, the northernmost extremity of the west Cumbrian iron orefield, and extends into the western slopes of the Lake District fells. The western boundary of the Lake District National Park lies less than 1 km east of much of the area, although about 2 km^2 around Lamplugh lie within the National Park.

The area is drained to the Irish Sea by the River Derwent and its major southern tributary, the Marron. The Derwent rises in the central Lake District draining Derwent Water, Bassenthwaite, Crummock Water, Buttermere and Loweswater. The Marron rises about 1 km south-west of Lamplugh and drains much of the district and the adjacent western slopes of the Lakeland fells.

The area north of the Derwent valley and much of that to the south towards Branthwaite and Lamplugh consists of rolling drift-covered country with numerous NE-SW drumlin ridges. This land reaches almost 120 m above OD north of the Derwent near Broughton Moor: south of the Derwent altitudes of just over 140 m above OD are reached between Eaglesfield and Dean. The broad flat floor of the Derwent valley rises from 32 m in the west to 38 m in the east. Although generally heavily concealed by drift deposits the outcrop of the Carboniferous Limestone may be traced along much of the eastern part of the area from Brigham, through Eaglesfield to Dean and Ullock. In places, most notably on Eaglesfield Crag and near Pardshaw, limestone scars and low crags are prominent landscape features and such characteristic features of limestone scenery as swallow holes and springs are common locally.

South of Branthwaite resistant outcrops of Coal Measure sandstones give rise to the steep sided plateaux features of Branthwaite Edge and Dean Moor which reach altitudes of over 180 and 215 m above OD respectively. East of Mockerkin and Lamplugh the ground rises sharply to the north-western Loweswater Fells at 248 m above OD at Mockerkin How and 409 m at Owsen Fell.

Apart from the rough upland grazing which characterises the higher ground of Dean Moor, Mockerkin How and Owsen Fell, much of the area is given over to pastoral farming with small areas under arable cultivation.

Three major roads cross the area, the A594 Maryport-Cockermouth, A66(T) Whitehaven-Cockermouth and A5086 Egremont-Cockermouth. In addition a complex network of unclassified roads connects the villages, most of which lie away from the main roads. A number of railways formerly served the area both for passenger and colliery traffic. All have long been dismantled. The course of the former Cockermouth-Workington line is followed through much of the area by the realigned A66 trunk road.

In common with much of the Cumbrian Coalfield, the area has a long history of coal production. All underground mining ceased many years ago although opencast extraction continues today at the Fox House site in the north-west of the district, and opencasting is expected to commence at the Broughton Lodge site in 1992. Prospecting of future sites was underway at a number of sites throughout the district during the survey.

Iron ore was worked underground at a few places. Clay ironstone from the Coal Measures was extracted, mainly last century, in the Branthwaite area. Hematite was mined from the Carboniferous Limestone near Lamplugh and trials were made last century for the same ore in the Eaglesfield area.

Limestone has been extracted from numerous quarries, with the largest at Broughton Crags, Brigham and Eaglesfield. Tendley Hill Quarry at Eaglesfield is the only active limestone quarry in the district today.

Several sandstone units have provided stone, mainly for local use, although none has been worked for many years.

Other mineral products recorded from the district include very small amounts of sand and gravel and brick and tile clays, the latter believed to have been obtained from the Coal Measures.

With the decline of extractive industries the district has resumed its essentially agricultural character. The former colliery villages of Broughton Moor and Great Broughton now serve mainly as dormitories for Workington, Cockermouth and beyond. Greysouthern, Eaglesfield, Dean and the district's other villages are dominantly farming settlements, in some cases with several farms within the same village. Many of these villages are becoming increasingly popular as residential areas for the urban centres of west Cumbria.

1.2 Data Sources

Several centuries of underground coal mining, together with the recent prospecting for opencast sites, has provided a wealth of geological data for the district. In compiling this report and accompanying maps data from the following sources were collated and interpreted:

* a detailed geological field survey at 1:10 000
* deep mine coal boreholes and shaft records
* deep mine coal abandonment plans
* opencast coal prospecting boreholes
* opencast coal completion plans
* site investigation boreholes, trial pits and reports
* existing geological maps
* Local Authority data
* geological reports and journals

The type, quantity, quality and limitations of each of these data sources are discussed in Appendix A.

Computerised databases of borehole and geotechnical information comprising more than 16 000 records (i.e. lines of data) were established. Their structure and value, both current and potential, are described in Appendix B. Both computer-aided and conventional techniques were used to produce the 1:10 000 scale standard geological maps, the 1:25 000 scale thematic maps and the accompanying reports.

1.3 Presentation of results

The results of the study are presented as a series of 1:10 000 and 1:25 000 scale maps, the latter listed in Table 1. Details of the districts' geology are described in Part 1 of the report and aspects of the applications for land-use planning and development are presented in this (Part 2) report.

1.4 Planning framework

Town and Country Planning aims to protect and enhance the environment, ensuring that the need to provide mineral and water resources, housing and industrial land is balanced against the need to conserve landscape, wildlife and historic sites. The safety of, and impact on, residents is also an important consideration in development plans.

Land-use and development plans are drawn up under guidelines set up at several levels. National policies are outlined in Planning Policy Guidance and Minerals Planning Guidance documents issued by the DOE. At the local level in West Cumbria, the Great Broughton-Lamplugh area is considered within planning documents issued by Cumbria County Council, the Lake District National Park, and Allerdale and Copeland district councils. The relevant planning documents affecting the Great Broughton-Lamplugh district are listed in Table 2.

Table 1 Titles and scope of 1:25 000 thematic maps which accompany this report.

MAP NUMBER	TITLE	DESCRIPTION
1	SOLID GEOLOGY	Major rock units, named coals, faults
2	DRIFT GEOLOGY	Superficial deposits (recent and glacial), made, landscaped and worked-out ground
3	ROCKHEAD ELEVATION	Contours at 10 m intervals on bedrock surface
4	DRIFT THICKNESS	Thickness of superficial deposits, contoured at 5 and 10 m intervals
5	GROUND STABILITY	Areas of known, probable and possible coal mining within 30 m of surface. Extent of known hematite iron ore workings. Extent of area known to be underlain by limestone. Sites of swallow holes
6	MADE AND DISTURBED GROUND	Areas of artificial ground, landscaped and other disturbed ground. Location of landfill sites
7	BOREHOLE AND SHAFT SITES	Locations of boreholes, shafts and adits
8	MINERAL RESOURCES AND EXTRACTION (EXCLUDING COAL)	Sites of past and present mineral extraction and extent of potential mineral deposits
9	GEOLOGICAL FACTORS FOR CONSIDERATION IN LAND-USE PLANNING	Significant elements from individual thematic maps presented together

In considering the potential resources which may be developed in an area and the constraints on this development, planners should take account of a number of geological factors. The principal geological resources are minerals. Planners need to know where potential mineral resources exist, in order to avoid, as far as possible, sterilising these, for instance by allowing built-up development above them.

The influence of development on water supplies, particularly the potential for contamination, could be a major constraint on development. Planners thus require information on sources of water supply and the interrelationship between these water sources and the geology.

Other geological factors may influence the feasibility of safe and cost-effective development. Stability factors such as subsidence into natural or man-made cavities, landslipping of natural slopes or of quarry faces, seismicity and foundation problems related to various types of made ground may need to be taken into account by planners.

Similarly chemical affects such as accumulation of gases, chemical deterioration of building materials and spontaneous combustion of waste material may also influence planning or development decisions.

This report outlines the geological resources and constraints which may be of significance in the Great Broughton-Lamplugh area. For planning purposes the report needs to be read in conjunction with the relevant planning documents listed in Table 2.

1.5 Limitations

This report and accompanying maps have been produced by the collation and interpretation of geological, geotechnical and related data from a wide variety of sources. However extensive this research may seem the data are not comprehensive and do vary in quality. In particular little hydrogeological or engineering data were available. It is inevitable that this variation in quality and quantity of data available will be reflected in the documents presented; local features and conditions may not be represented and many boundaries may be only approximate.

The aim has been to produce a general description of the geological factors which are relevant to land-use planning and development. This report and associated documents can contribute to drafting and evaluating structure and local plan policies. This may alert planners, engineers and developers to opportunities or constraints by highlighting particular aspects of the geology of the district but they cannot and should not replace site-specific surveys aimed at evaluating potential resources or problems. Users must satisfy themselves, by seeking appropriate professional advice and by carrying out ground surveys, that conditions are suitable for any particular land use or development.

Table 2 Planning documents relevant to the Great Broughton-Lamplugh area.

1	**Department of Environment Documents.**
Planning Policy Guidance Notes.	
PPG1	General Policy and Principles
PPG3	Land for Housing
PPG7	Rural Enterprise and Development
PPG12	Local Plans
PPG14	Development on Unstable Land
PPG15	Regional Planning Guidance, Structure Plans and the Content of Development Plans
Minerals Planning Guidance Notes	
MPG1	General conditions and the Development Plan System
MPG2	Applications, Permissions and Conditions
MPG3	Opencast Coal Mining
MPG4	The Review of Mineral Working Sites
MPG6	Guidelines for Aggregates Provision in England and Wales
MPG8	Planning and Compensation Act 1991: Interim Development Order Permissions (IDOS) — Statutory Provisions and Procedures
2	**Cumbria County Council Documents**
Cumbria and Lake District Joint Structure Plan Explanatory Memorandum 1988 and Key Diagram.	
Cumbria and Lake District Joint Minerals Local Plan (excluding Coal) Written Statement and Proposals Map. (1986)	
Cumbria Coal Local Plan Written Statement and Proposals Map. (1991)	
3	**Allerdale District Council**
Southern Allerdale Local Plan	
4	**Copeland District Council**
North East Copeland Local Plan	

The maps were constructed in February 1991. No information subsequent to that date has been taken into account.

1.6 Confidentiality

Confidential data, chiefly British Coal Opencast Executive prospecting information, has been taken into account and used in a generalised way during the preparation of the geological maps, but details of specific boreholes are not individually quoted.

1.7 Acknowledgments

The help and cooperation of the following are gratefully acknowledged:

British Coal Deep Mines and Opencast Executive.
Tendley Hill Quarries Ltd.
Cumbria County Council.
Landowners and tenants in the survey area.

2 GEOLOGICAL SUMMARY

2.1 **Introduction**

The geology of the district is described in detail in Part 1 of this report. The following is a very abbreviated account of the salient features intended to provide sufficient background to place in context the subsequent sections dealing with land-use planning elements.

The district's geology may be conveniently considered in two parts. Firstly those deposits known as 'solid'. In this area these comprise rocks which range in age from Ordovician (510–438 million years old) to Carboniferous (300–320 million years old). The disposition of the solid formations is shown in Figure 2 with details of the solid succession in Figures 3, 4 and 5. Greater detail may be seen on 1:25 000 scale Map 1 or the three component 1:10 000 scale maps which cover the district.

Quaternary or 'drift' deposits are less than 18 000 years old and form a discontinuous, generally unconsolidated layer, up to 20 m thick covering the solid rocks. The disposition of the drift formations is shown in Figure 6. Greater detail may be seen on 1:25 000 Map 2 or the three component 1:10 000 scale maps which cover the district.

2.2 **Solid Geology**

2.2.1 Ordovician Rocks

Rocks of the Skiddaw Group, which is Ordovician in age, crop out in the east of the district. These rocks were deposited as turbidity currents (a 'slurry' of sediment and water which behaves as a discrete fluid phase) which flowed along the floor of the depositional basin. The deposits of turbidity currents are called turbidites. A complete turbidite will show a change in grain size from coarse sand at the base of the unit to fine-grained mud at the top. The ratio of coarse to fine-grained material in a turbidite changes with distance from the source of the sediment. The further away from the source the finer the sediment, as coarse material will fall out of suspension first.

In the Great Broughton-Lamplugh district the Skiddaw Group is dominated by siltstones. Mudstones and occasional sandstones are also present.

2.2.2 Carboniferous Rocks

Cockermouth Lavas

The Cockermouth Lavas are restricted in their occurrence to a NE-SW trending strip extending from Papcastle north-eastwards to Bothel. The lavas are exposed in the bed of the River Derwent at Stoddart Hole [0986 3113]. The lavas are olivine basalts. They are vesicular with cavities filled with both calcite and quartz.

Chief Limestone Group

The Chief Limestone Group is Dinantian to lower Namurian in age. The Chief Limestone Group can be divided into seven separate limestone units named the First to Seventh Limestones (Figure 3). The First Limestone is at the top of the sequence and hence the youngest, the limestones being numbered from the top down in the order they were reached during exploration and mining for iron ore. Individual limestone units vary in thickness from 85 m (Fourth Limestone) to 5 m (Third Limestone). In the present study area the Fifth to Seventh Limestones could not be consistently differentiated and thus they are represented as a single unit on the geological maps.

The limestones show a range of lithologies. Most are wackestones or packestones of Dunham's (1962) classification. No individual limestone unit is lithologically distinct however, though specific fossiliferous beds may be recognised within the Fourth Limestone. The limestones vary in colour from cream to dark grey. The limestones may be dominated by either mud or crystalline carbonate with fossil fragments, dominantly crinoid columnals and brachiopods, present locally. Beds are up to 1 m in thickness and bedding surfaces are either planar or wavy; mudstone partings occur between limestone beds. Chert nodules occur in the Fourth Limestone.

The individual limestone units are separated by mudstone or sandstone dominated beds. The thickest interval is between the Second and Third Limestone, which is dominated by thickly bedded sandstones which have been termed the Orebank Sandstone. The Orebank Sandstone is up to 15 m in thickness in the Great Broughton-Lamplugh district. A sandstone unit also occurs directly beneath the First Limestone. This sandstone is called the Little Whirlstone.

Excellent sections through many of the limestones may be seen in numerous abandoned quarries and natural outcrops. The First Limestone is well exposed in the large working quarry at Tendley Hill, Eaglesfield [088 289].

Hensingham Group

The Hensingham Group occurs between the First Limestone and the Coal Measures (Figure 4). The group is Namurian in age. The basal units of the Hensingham Group are dominantly sandstone and these beds have been termed the Hensingham Grit. The Hensingham Grit is exposed in a number of quarries at Brigham [083 302] where it is a buff to white, fine- to medium-grained sandstone. The Hensingham Grit becomes flaggy towards the top of the exposed quarry faces.

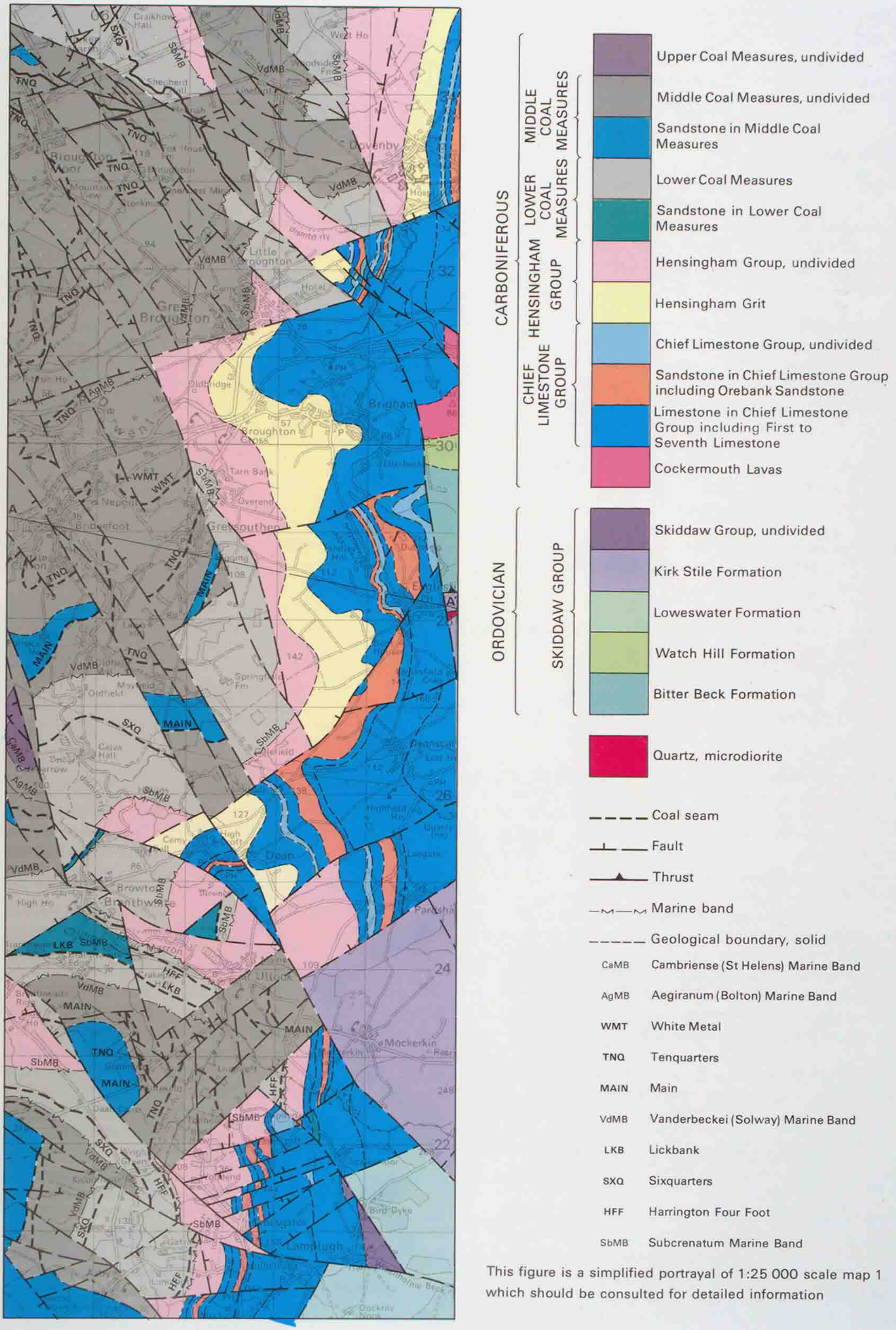


Figure 2 Solid geology map.

Figure 3 Generalised vertical section of Chief Limestone Group

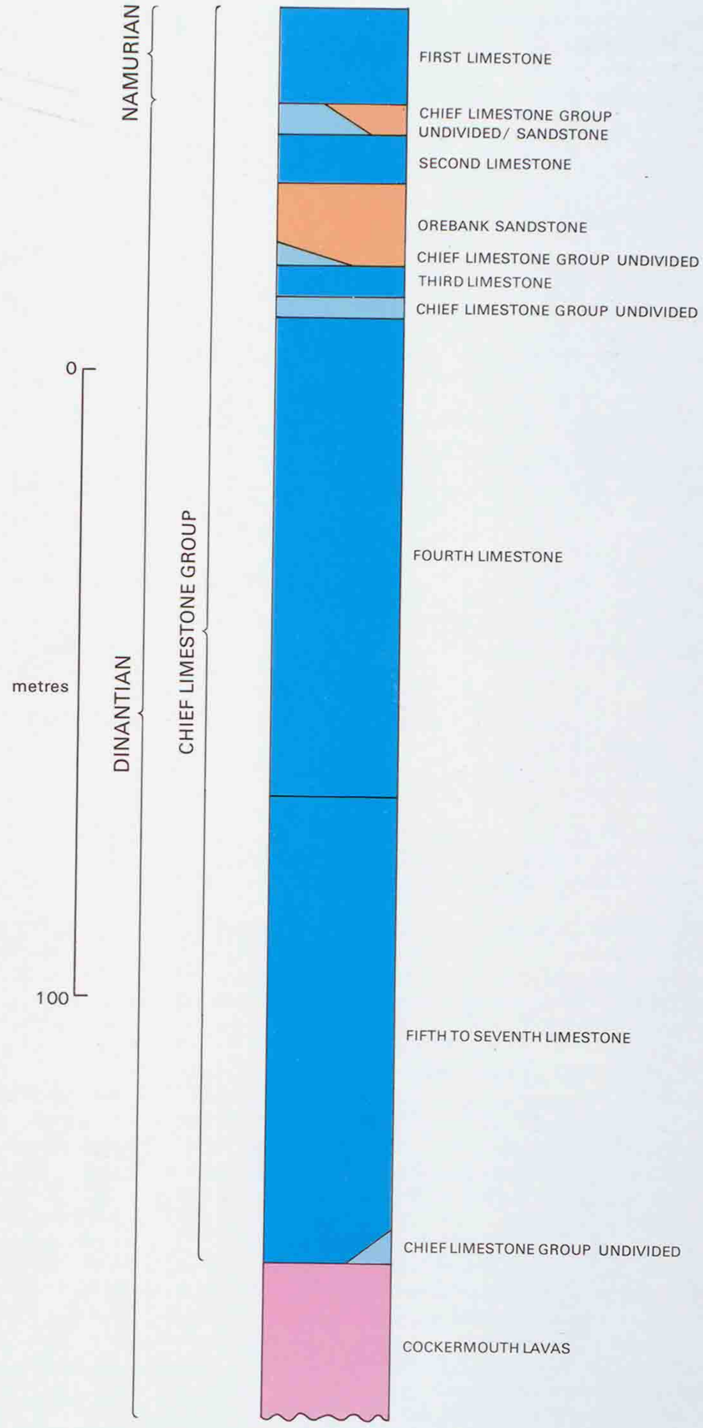


Figure 4 Generalised vertical section of Hensingham Group

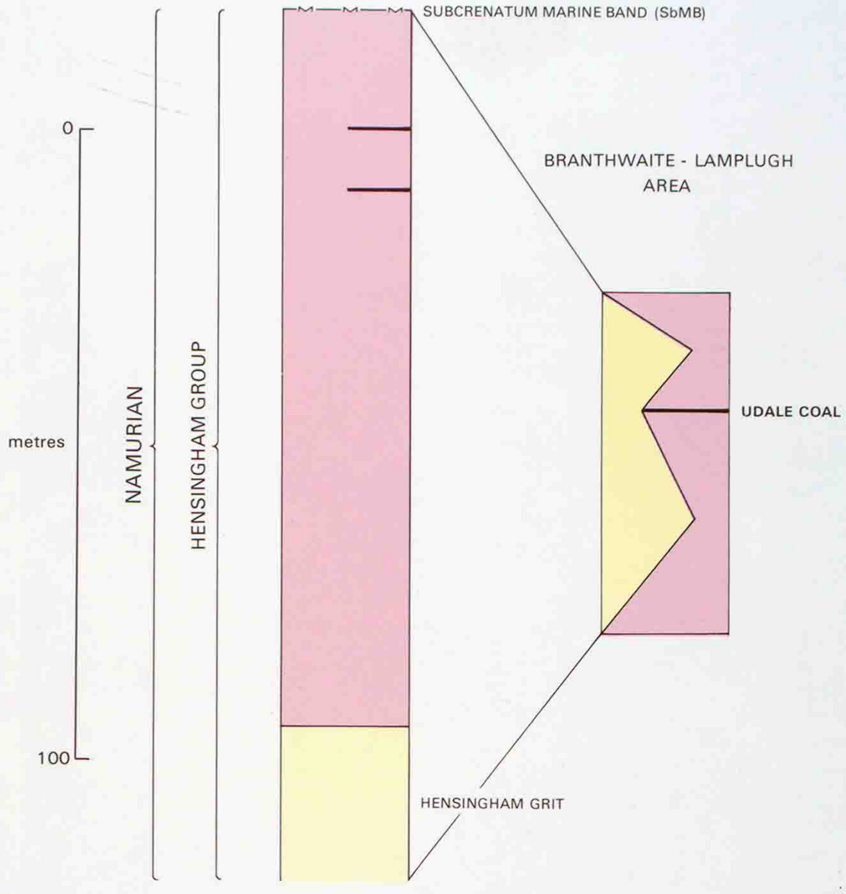
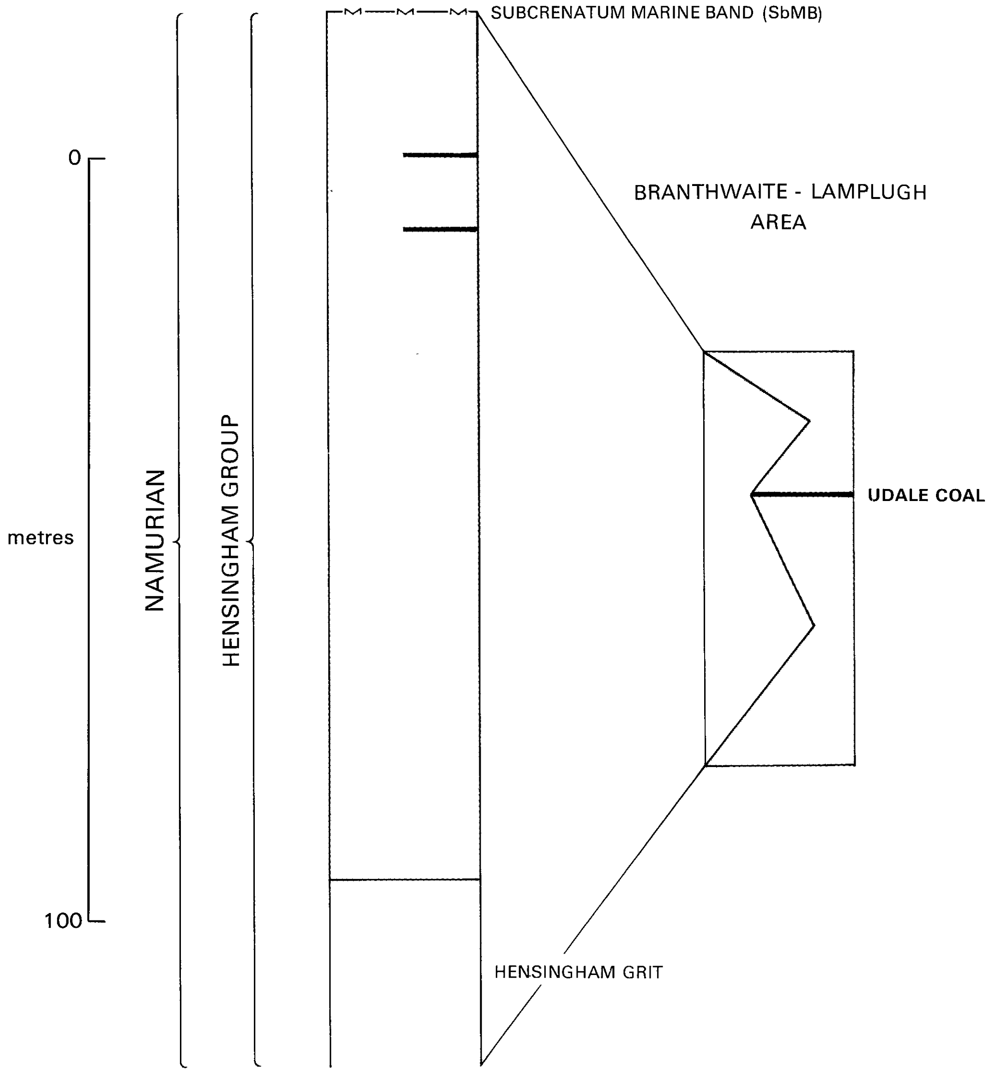


Figure 4 Generalised vertical section of Hensingham Group



Above the Hensingham Grit the Hensingham Group consists of interbedded sandstones, siltstones and mudstones, with occasional limestone and coal beds. A named coal, the Uldale, occurs towards the top of the Group.

Coal Measures

The Coal Measures were deposited in a predominantly deltaic environment during Westphalian times. The succession in West Cumbria is up to 350 m in thickness, and is dominated by mudstone, siltstone and sandstone with occasional coals and seatearths.
The individual lithologies are as follows:

Mudstone Mudstones are light to dark grey in colour and have a maximum grain size of less than 0.004 mm. The mudstone may be fossiliferous and occasionally rich in organic material. They may contain clayed ironstone nodules. The nodules form, by diagenetic segregation of siderite which may be present as a minor constituent of the mudstone. Nodules are on average 10–20 cm in size and, in places, were formerly worked as iron ores.

Sandstones and siltstones Coal Measures sandstones are normally buff to cream in colour. In west Cumbria some sandstones high in the sequence may locally be red due to secondary alteration. Sandstones vary from fine to very coarse-grained. Depending on their mode of deposition sandstone units may occur either as lenticular bodies tens of metres wide or as laterally extensive sheets. Individual sandstone units vary in thickness from 1–45 mm.

Seatearths (fireclay or ganister) Seatearths represent the soil layer on which vegetation grew and hence they are typically found underlying coals. Seatearths are generally more persistent than their associated coals. No relationship exists between the thickness of the seatearth and of the overlying coal. Like present-day soils, seat earths vary in composition. The seatearth may be composed predominantly of sand. When this has developed a siliceous cement the rock is germed ganister. Some seatearths are composed of clay. When these are kaolinite-rich the rock is termed a fireclay. Seatearths typically contain abundant rootlets which have destroyed or disrupted the original bedding.

Coals Coal seams formed from the vegetation which grew in swamps on the delta plain. There are up to 29 named seams in the Cumbrian coalfield, all of which have been worked by either deep mining or opencasting. The seams may be up to 3 m in thickness. Individual seams may occur as

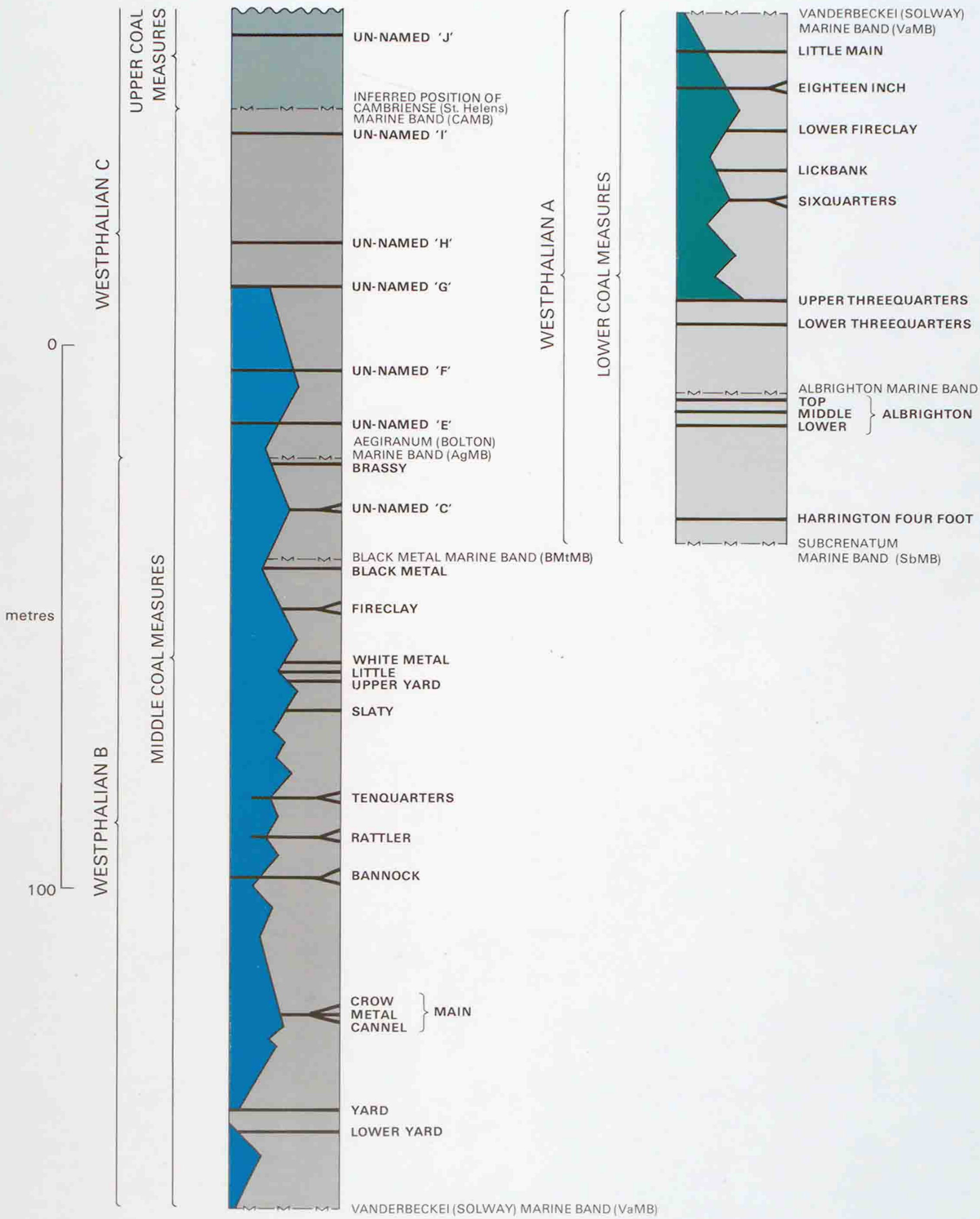
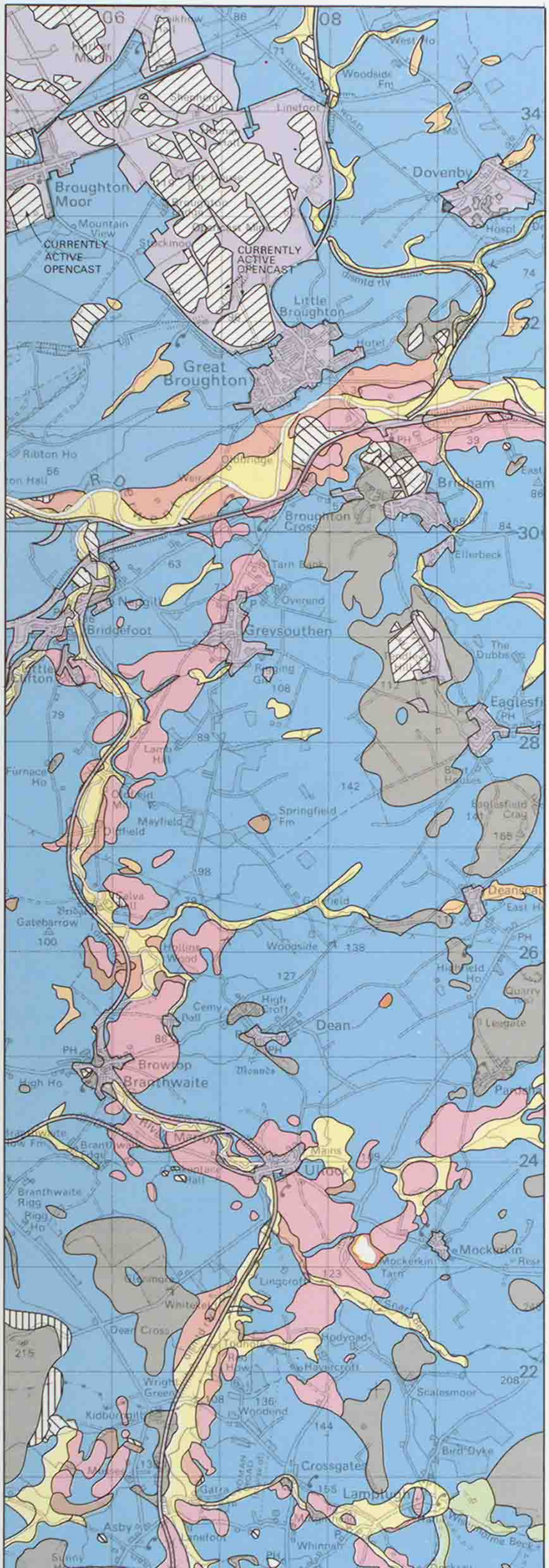


Figure 5 Generalised vertical section of Coal Measures



KEY

Landslip

Peat

Alluvium: a variable sequence of clay, silt, sand and gravel. May include peat locally

River terrace deposits: similar to alluvium. Distinguished by occurrence as elevated terraces

Lacustrine deposits: mostly clay, silt and some gravel. May include peat locally

Glaciofluvial deposits: sand and gravel

Morainic deposits: heterogeneous glacial debris characterised by markedly hummocky surface

Till (boulder clay) and glacial drift, undifferentiated: mainly stony and sandy clay

Solid rock, undifferentiated

Worked-out opencast coal seam area or quarry in solid rock

Made ground (Solid and drift boundaries below made ground based on old records)

Worked-out ground and made ground

Landscaped ground, eg areas around opencast sites

(See also Fig 11, Made and Disturbed Ground)

This figure is a simplified portrayal of 1:25 000 scale map 2 which should be consulted for detailed information

Scale
0 1 2 3
kilometres

Figure 6 Drift geology map

Table 3 Correlation of local seam names with seam nomenclature used in this report

MOORSIDE COLLIERY	DEAN MOOR COLLIERY	ASBY COLLIERY	BGS SEAM NOMENCLATURE
Rough	Dean Moor Upper Coal		Slaty
Anthony Wiley		Bannock Band	Ten Quarters
Eighteen Inch	Galloway Band	Rattler	Rattler
Yard	Dean Moor Lower Coal	Yard Band	Bannock

either single or, where beds of clastic sediment intervene, as split seams. Splits may be being developed locally or in some instances over a wide area. In some cases the individual leaves of the split seam have been named, e.g. the Main Band is subdivided into the Cannel, Metal and Crow.

Care must be taken in accepting seam nomenclature from old plans, borehole logs or other data sources. Both homonyms (different seams being given the same name, e.g. Yard) and synonyms (the same seam being given different names e.g. Slaty and Rough) occur (Table 3).

2.2.3 *Structure*

Throughout much of the district bedding dips gently (more than 20°) to the west.

The area is heavily faulted. The dominant trend of the faults is NW-SE with subordinate NE-SW and east-west striking faults. The majority of faults have normal displacements, although some strike-slip (lateral) displacement directions have been recognised. Normal displacements of up to 350 m have occurred on some faults, e.g. the Mockerkin Fault. Open folds developed in conjunction with the faulting.

2.2.4 *Intrusive igneous rocks*

A dyke, estimated to be up to 75 m wide, which intrudes the Skiddaw Group, has been mapped to the east of Eaglesfield. The rock is a fine-grained microdiorite. When fresh it is light grey to pale fawn in colour but weathered surfaces are reddish- brown.

2.3 Drift geology

Bedrock is overlain over much of the area by unconsolidated deposits, usually known as drift. The drift is of variable thickness and is absent in places. Here, the bedrock is present beneath a thin soil profile or is exposed at the land surface. The upper surface of the bedrock is known as 'rockhead'. This rockhead surface corresponds to the land surface where drift deposits are absent but, elsewhere, is at a depth equal to the thickness of the drift. The form of this rockhead surface, as inferred from the logs of boreholes and field observations, is shown in Figure 7 and in more detail on 1:25 000 scale Map 3. The rockhead surface may be taken to be the pre-Quaternary landscape, on which was deposited the mantle of drift deposits. This surface very broadly mirrors the present-day land surface, although the form of certain features, perhaps most notably the courses of the major rivers Derwent and Marron, differ slightly; where drift deposits are absent the rockhead surface obviously corresponds to the modern land surface.

The overall thickness of drift deposits is shown in Figure 8 and on 1:25 000 scale Map 4. From this it will be seen that over much of the district the drift is less than 20 m thick and there are wide areas, especially in the east, where drift deposits are consistently less than 5 m in thickness. Drift deposits are commonly absent from the higher hills especially in the east and south of the district. In addition post glacial erosion by the rivers Marron and Derwent have locally cut through the drift deposits exposing areas of 'solid' rock on the steep valley sides.

Whereas much of the drift comprises deposits laid down during or immediately after the last glaciation there are some deposits, e.g. alluvium and river terrace deposits, which are of more recent origin.

The following notes provide a brief guide to the main characteristics of individual drift deposits. For greater detail reference should be made to the Geology report.

Till Till or boulder clay is the most widespread single drift deposit, although good natural exposures are few. The deposit is typically a variable mixture of clay, sandy clay or clayey sand in which occur a large number of cobbles or boulders, in places up to 1.5 m across or even larger locally. Much of the till appears to be less than 20 m in thickness although greater thicknesses may be present south-west of Great Broughton, and near Branthwaite and Ullock. Thin lenses of sand and gravel may be present locally within the till.

Glaciofluvial deposits These comprise the deposits previously mapped as glacial sand and gravel. They form a belt of discontinuous outcrops along parts of the Derwent and Marron valleys as well as a number of comparatively wide spreads to the north and north-west of Mockerkin. These deposits comprise a variable mixture of sands and coarse to fine gravels. No reliable maximum thicknesses are known but the deposits are unlikely to exceed a few metres.

Alluvium Belts of alluvium flank most of the course of both the rivers Derwent and Marron as

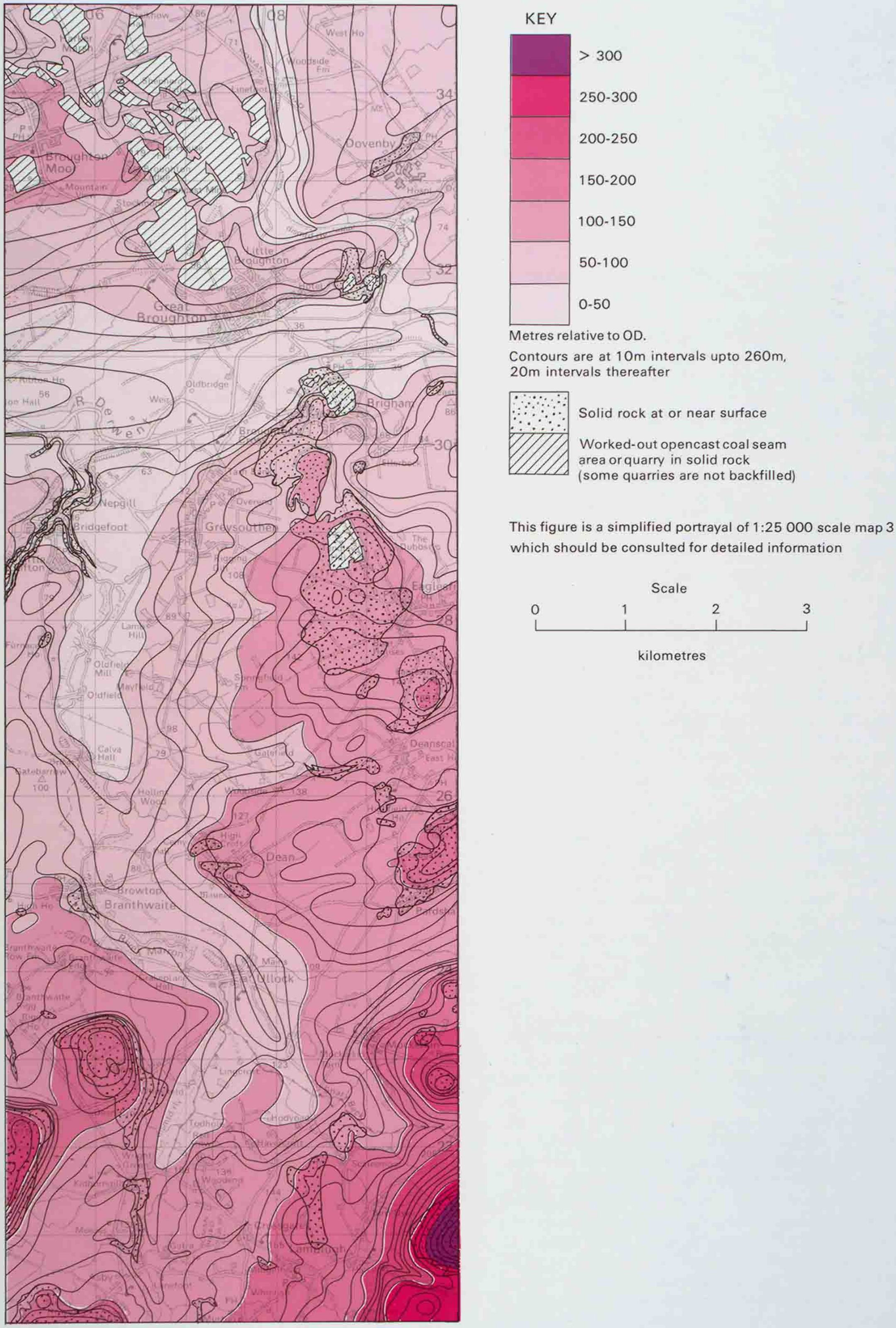


Figure 7 Rockhead elevation map

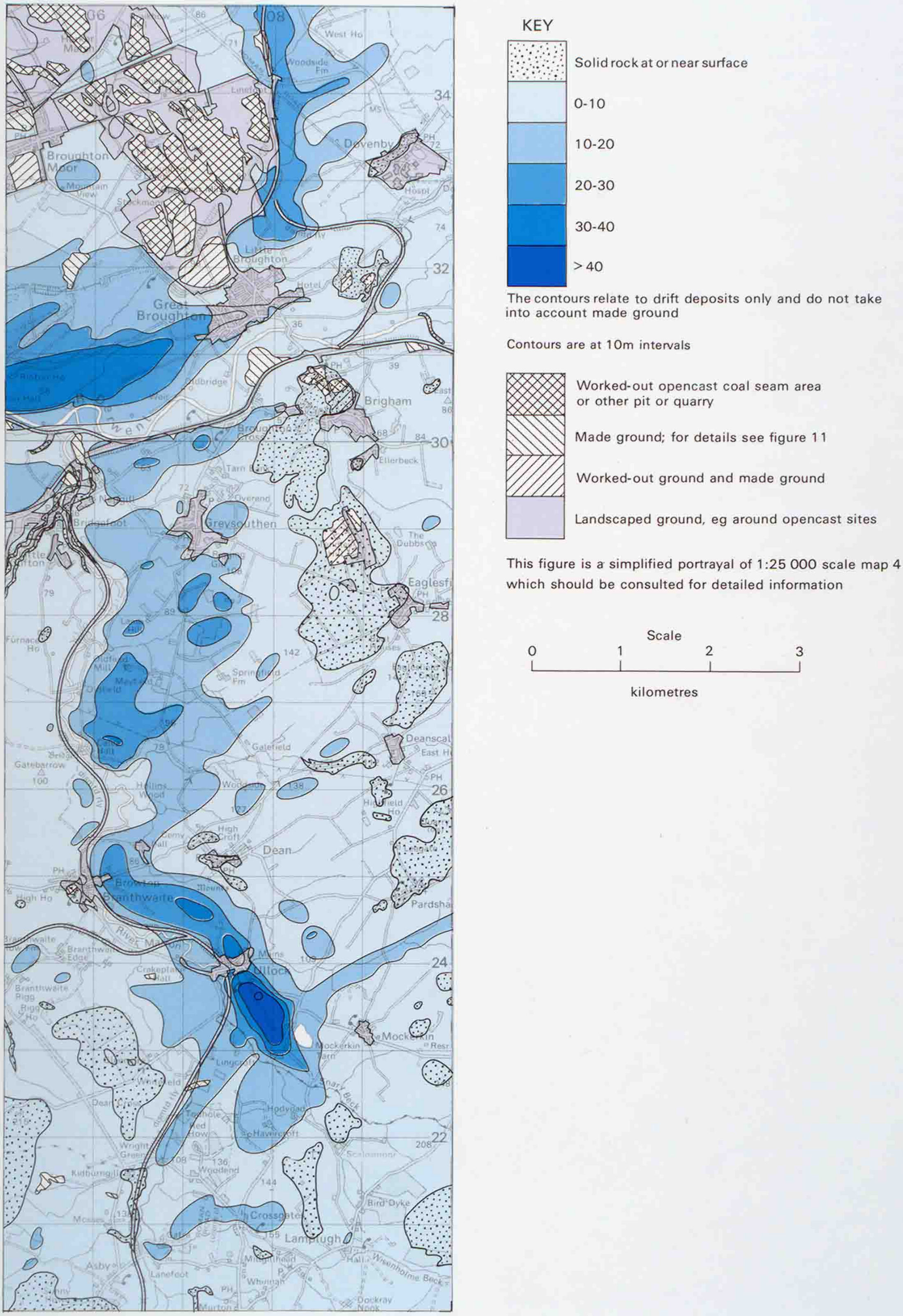


Figure 8 Drift thickness map

well as some minor streams. These deposits consist mainly of silts, clays, sands and gravels. Thin beds of peat or peaty clay may be present locally within the alluvial deposits.

River Terrace Deposits These have been identified at a number of places along the rivers Derwent and Marron. Like the alluvial deposits they appear to consist principally of silts, sands and gravels. They may locally be cemented into comparatively hard deposits by iron and manganese oxides.

Lacustrine Deposits Isolated areas of silty alluvium which fill enclosed basins, formerly occupied by small lakes, occur in a number of places throughout the district. These deposits are unlikely to exceed 2 m in thickness.

Alluvial Fan Deposits Small fans, composed of silts, sands or gravels occur locally where tributary streams join main valleys. These deposits are unlikely to exceed 4 m in thickness in the district.

Peat Peat occurs filling shallow enclosed basins, mainly in the southwest of the district south of Branthwaite, although small areas occur elsewhere. In places thin beds of peat or peaty clay or silt have been recorded within the alluvium. None of the district's peat is likely to exceed 1.5 m in thickness.

3 GEOLOGICAL RESOURCES FOR DEVELOPMENT

3.1 Introduction

At least nine different mineral products have been extracted from the district. These are described below, and the sites of workings, and where appropriate, the location of the deposits, are delineated on Map 8 and Figure 9.

An appreciation of the nature and extent of previous workings is an essential basis for understanding the present and likely future potential of a mineral. In the following pages the salient features of the minerals' occurrence and the history, if any, of working are briefly described and the resource potential assessed.

Coal continues to be the region's most important mineral product but considerable quantities of limestone are still produced from the one remaining active limestone quarry. A variety of other minerals such as iron ore, ganister, building stone and sand and gravel, have been produced in the past, generally in much smaller amounts. There are currently no permanent workings for any of these.

Resources of these and other minerals may well exist within the district. The likely extent of these and, where appropriate, the potential for further extraction are discussed below. It must be noted, however, that no systematic assessment of any individual mineral or deposit has been undertaken during the present survey.

A brief account of the district's hydrogeology is included in this section. Pollution and the effects of mining are dealt with in Section 4.

3.2 Coal

3.2.1 Occurrence

Coal seams of economic significance occur almost entirely within the Lower and Middle Coal Measures, the combined thickness of which is about 300 m in the district. Approximately 20 main seams have provided most of the production. All of these are known to vary in thickness and quality throughout the district and they are not all economically workable in all places. Minor seams, and local splits of the main seams, assume importance locally. In places even the better seams deteriorate in thickness or quality and locally may have been either partially or completely removed by washouts (known locally as 'nips'). Washouts particularly affect the Main and Sixquarters seams. Shale or dirt partings adversely affect the quality of some seams and in places may render them uneconomic. Pyrite (FeS_2), present in abundance in some seams, e.g. the Brassy, is an undesirable contaminant especially in view of the increasing demand for low sulphur coal.

Most of the Cumbrian seams yielded bituminous coals of high volatile content and with strong caking properties, perhaps best described as 'general purpose' coals. They were well suited to coking, gasmaking, steam raising and household use. Few recent analytical data have been published although Taylor (1978, p.185) notes that volatile contents calculated on a dry ash-free basis vary from 32 to 39 per cent. Jones (1957, pp.83–84) gave brief descriptions of the characteristics of Cumbrian coals.

3.2.2 History of exploitation

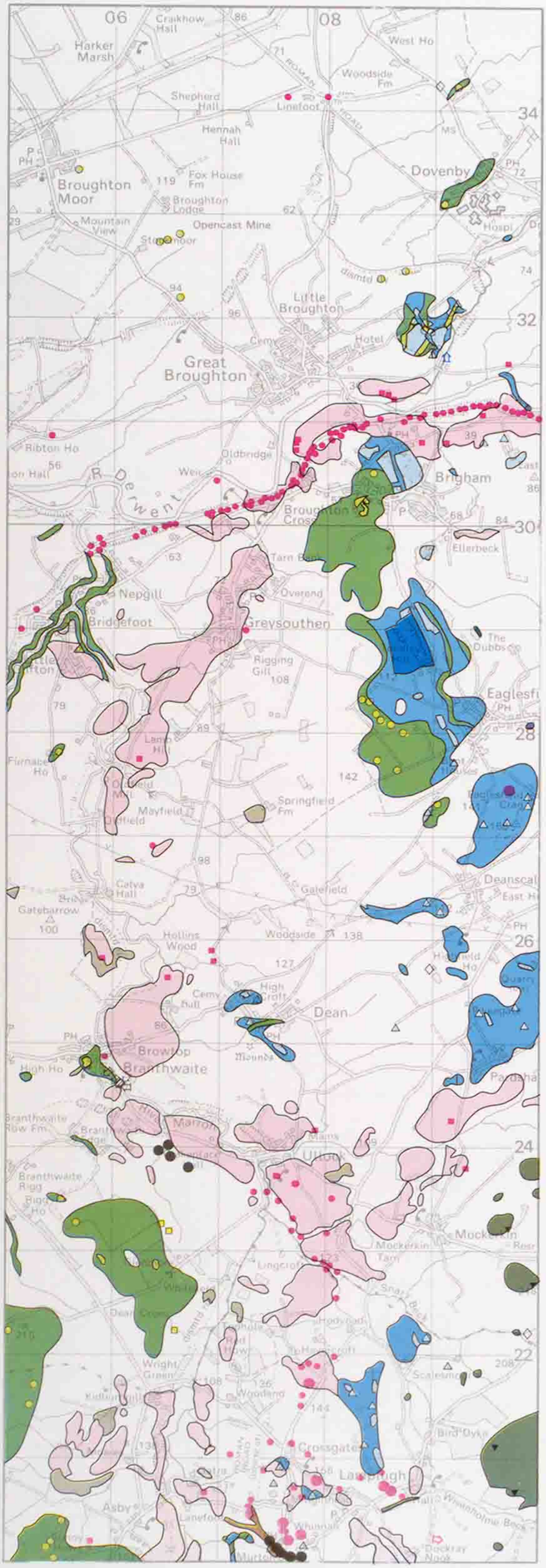
The Cumbrian Coalfield, of which the present district forms part, has had a long history as a coal producer. Documentary records exist of coal working from the mid-sixteenth century. The heyday of coal mining was during the latter half of the nineteenth and first half of the twentieth centuries. The large reserves of coking and steam raising coal combined with the nearby abundance of high grade hematite iron ore, formed the basis of the heavy industrial economy of west Cumbria. The district described in this report also include the northernmost part of the west Cumbria iron ore field. A considerable portion of the coalfield's output was exported through the formerly large coal handling port of Maryport.

The history of coal mining in Cumbria has recently been traced in detail by Wood (1988).

An outline of coal mining methods employed in the area is given in section 4.2.1 of this report.

The date of the earliest coal working within the district is not known. Almost certainly the earliest workings were open pits and small adits driven into a seam outcrop from a valley side or other convenient point. The earliest shaft mining consisted of bell pits. These were unlikely to have exceeded 15 m in depth. From these an area of coal, perhaps little more than 20 m wide, was extracted before the pit was abandoned and a new one sunk nearby. Although the areas of working from these early operations were comparatively small, it is likely that rates of extraction were high with, in places, relatively little coal left unworked.

As mining techniques advanced workings became larger and more systematic. Progressively deeper seams became workable, especially as better pumping and ventilation methods were adopted. The pillar and stall system was widely practised with extraction rates of up to 50 per cent. Panel working was probably introduced into some collieries early in the nineteenth century. This method, which enabled a greater level of extraction to be achieved, commonly involved reworking or 'robbing' earlier pillar and stall workings. The longwall system eventually replaced these earlier



KEY

- Sand and gravel deposit at surface
- Borehole proving > 1 metre of sand and gravel with overburden ratio of < 3:1
- Sand and gravel pit, abandoned Some of these pits are very small and consequently have not been depicted on Map 6
- Brick or clay pit, abandoned.
- Peat
- Sandstone at surface
- Sandstone quarry, abandoned
- Sandstone quarry, abandoned. Quarry too small to show true extent at this scale
- Limestone at surface
- Limestone quarry, active
- Limestone quarry, abandoned
- Limestone quarry, abandoned. Quarry too small to show true extent at this scale
- Cleaved siltstone at surface
- Cleaved siltstone quarry, abandoned. Quarry too small to show true extent at this scale
- Igneous rock at surface
- Pit, abandoned, mineral extracted unknown Quarry too small to show true extent at this scale
- Ironstone shaft, abandoned
- Ironstone adit, abandoned showing direction of entry
- Hematite shaft, abandoned
- Hematite adit, abandoned, showing direction of entry
- Extent of known underground workings for hematite.
- Trial adit for copper, direction of entry unknown

This figure is a simplified portrayal of 1:25 000 scale map 8 which should be consulted for detailed information

Scale
0 1 2 3
kilometres

Figure 9 Mineral resources map

methods allowing the highest rate of coal recovery. This was the method almost universally adopted in the final years of underground mining. Deep mining came to an end in the district with the abandonment of Dean Moor Colliery in 1951 (Table 4).

The increased demand for coal during World War II gave impetus to exploration for opencast coal. A considerable amount of investigation was undertaken in Cumbria but production did not begin within the present district until 1958 at the Broughton Moor site. Since then several large sites have been worked in the northern part of the district around Broughton Moor, as well as in the southern part of the coalfield (Table 5).

Opencast coal is won both from virgin seams and virgin areas of seams worked elsewhere. Much of this coal comes from seams high in the Coal Measures sequence. Reworking of ground, previously mined by underground methods, is also important.

Considerable tonnages of coal have been won from blocks of coal left either as pillars in old workings or as unworked areas between collieries or within unworked districts of collieries. Opencast mining is currently (1991) in progress at the Fox House North-west [053 332] and Fox House South [065 327] sites.

Prospecting for further reserves of economically recoverable opencast coal has been undertaken throughout much of the coalfield including the present district.

Most of the coal won from opencast operations in Cumbria is currently transported by lorry to a central stock yard, blending and despatch facility adjacent to the railway at Maryport. From here it is distributed to its various markets by road, rail and sea, the latter via Workington harbour. In 1988–1989 the destinations for Cumbrian coal were as follows:-

Power stations 44%
Export via Workington
— mainly for cement
manufacture in Ireland 34%
Collieries — for blending
with coal produced from
deep collieries in the
Manchester area 16%
Local industry 6%

3.2.3 Resource potential

Despite the long history of coal extraction, further resources exist within the district. Included here are blocks left unworked during previous mining for a variety of reasons such as seam thickness or quality, or structural position within a colliery or royalty area. Substantial quantities of coal are likely to be present as pillars and similar residual blocks left as support during previous mining.

Under the present and foreseeable future economic climate any resumption of underground mining for coal within the district is very unlikely. There is, however, considerable scope for opencast extraction, though the viability of any proposal will of course be dependent upon a broad range of economic conditions.

Table 4 Mines with a take in the district with dates of abandonment.
(NB The date of abandonment on which abandonment plans were deposited is not necessarily the date of cessation of mining.)

COLLIERY and *individual shafts or sections*	Date of abandonment
OUTFIELDS; *Alice Nos 1 and 2*	1921
BROUGHTON MOOR: *Bertha, Nos 1, 2 and 3*	1925
Henry, Engine	Unknown
Mary	1871
Brough, Standingstone	Unknown
ROAD END	1846
FOLLY	1889
DOVENBY	1894
DOVENBY CLOSE	1891
BUCKHILL	1932
MELGRAMFITZ: *Mary, Whittaker*	1880
MOORSIDE	1899, 1943
BRANTHWAITE	1923
DEAN MOOR, *Nos. 1 and 2,*	1951
Bird	1931
ASBY	1908
FORTUNA	1934
LOWTHER	1894
LONSDALE	1894
GREYSOUTHEN: *George, Hope*	1823
Engine, Nepgill, Newbanks	1960
Mary	Unknown
LAMPLUGH	1880
CLIFTON: *Little Clifton, Lowther, Nepgill, Stainburn*	1960
HARRYGILL: *Bridgefoot*	Unknown
CROSSBARROW: *Chapel Brow, Lowther Close*	Unknown
IRON ORE MINES and *individual shafts*	
LAMPLUGH: *Coronation, John Wood, Winnah and Murton*	1931

Table 5 Open cast sites within the district

Broughton Moor	completed 1959
Blooming Heather plus extensions D and D1	completed 1969
Blooming Heather extensions E, F, G and H	completed 1974
Woodside	completed 1982
Low Close - Foxhouse	completed
Foxhouse South	active
Foxhouse North West	active
Broughton Moor (new site)	active

At the time of writing (April 1991) opencast mining is under way at two sites in the north of the district (see above), while planning application has been made for a future site at Lostrigg south of Little Clifton and prospecting has been carried out at other sites.

Planning and environmental factors concerning future coal working in Cumbria are discussed in Cumbria Coal Local Plan (Cumbria County Council: 1989).

The general location of coal resources can be deduced from a study of the 1:25 000 maps which accompany this report, the three component 1:10 000 scale geological maps and Part 1 of the report which contains notes of seam thicknesses and other characteristics.

3.3 Limestone

3.3.1 Occurrence

Limestone is the district's second most important mineral product after coal. Much of the Lower Carboniferous (Dinantian) and lower part of the Namurian sequence consists of limestone. Wide outcrops of limestone extend almost continuously from north to south across the district, although a variable thickness of drift deposits, mainly till or boulder clay, conceals much of this. Within those areas which are drift free, or which have only a comparatively thin drift cover, old limestone quarries are often conspicuous. These range from small pits which provided small quantities of stone for local use, either for building or lime burning, to much more extensive workings which supplied limestone for a variety of end uses, mainly outside the district. One large quarry, at Tendley Hill [088 289] is still working.

Small quarries exist in all of the district's limestone units though large scale production has come mainly from the First Limestone with significant though smaller quantities from the Fourth Limestone. The distribution of drift-free limestone outcrops and limestone quarries is shown on Map 8.

3.3.2 History of exploitation

The earliest local uses of limestone were for burning to produce quicklime and mortar. Appreciable quantities were also employed locally in drystone walling. Very little was employed as building stone; the relatively abundant and more easily dressed sandstones were preferred for this purpose. With the rise of iron smelting during the last century the sharp increase in demand for limestone flux was met by many quarries in west Cumbria. In the present district large quarries developed at Broughton Crags, in the First and Fourth Limestones and around Brigham and Tendley Hill in the First Limestone. In addition to limestone flux the Brigham quarries had kilns for the production of quicklime.

At the district's sole surviving limestone quarry at Tendley Hill [088 289] the full thickness of the First Limestone is worked entirely as a source of aggregate and roadstone, the quarry having a tarcoating plant. Overburden is small and, subject to land and mineral ownership and planning constraints, considerable reserves of limestone remain to be worked.

3.3.3 Resource potential

No systematic study of limestone composition or properties has been undertaken during this survey. Considerable resources of limestone which could provide future sources of aggregate and roadstone may be identified both in the First Limestone and in parts of the lower units. No deposits of high purity limestone suitable for chemical manufacture are known within the district.

Apart from planning and environmental considerations, the establishment of new limestone quarries or extensions to existing quarries is dependent upon rock quality, overburden thickness and local geological structure.

3.4 Sandstone: Building stone

3.4.1 Occurrence

Sandstones form an important part of the Coal Measures, Hensingham Group and Chief Limestone Group sequences. A variety of sandstone types are present. Some have been worked in the past, mainly for building stone. A smaller quantity of the siliceous sandstone known as ganister has also been worked from Coal Measures sandstones for use as refractories (see section 3.5).

The distribution of drift-free sandstone outcrops and sandstone quarries is shown on Map 8.

3.4.2 History of exploitation

Although many of the small sandstone quarries no doubt provided only comparatively small amounts of stone for local use such as farm building construction and dry stone walling, a few quarries produced freestones of sufficient quality to be marketed outside the district. No sandstone has been produced from the district for many years.

The most important and largest sandstone quarries were those at Broughton Crags [090 318] and Brigham [083 302]. The Orebank Sandstone at Broughton Crags is a medium-grained rock in which cross-bedding is locally conspicuous. At Brigham Quarries the Hensingham Grit which is here a medium- to coarse-grained thickly bedded sandstone has been worked in several large pits.

No production figures are available for either of these groups of quarries though clearly a considerable amount of stone was produced. The date of the workings is unknown.

Smaller quarries for building stone were worked on Branthwaite Edge [0595 2290 and 0644 2287] on the hillside above Moorside Colliery [0528 2170] and at Salter Park [0585 2008]. These quarries worked a medium- to coarse-grained pink Coal Measures sandstone. The precise stratigraphical position of these sandstones, which were termed Whitehaven Sandstone in earlier accounts of the district's geology, is discussed in the Geology report.

3.4.3 Resource potential

The sandstones of the district are unlikely to be attractive to the modern dimension stone trade and a resumption of quarrying for building stone is very unlikely. Some sandstone may be saleable as crushed rock produced as a by-product of coal or limestone working.

3.5 Sandstone: Ganister

3.5.1 Occurrence and history of exploitation

Siliceous sandstone or ganister was formerly mined from the Sixquarters Rock at Branthwaite Colliery [059 253]. Much of the output from these workings consisted of wet and dry ground ganister made from a mixture of the ganister and fireclay which was also worked here (see Section 3.6 below) (Anon, 1920B, p.15–16).

Other ganister sandstones are present with the Coal Measures, Hensingham Group and locally within the Chief Limestone Group of the district. There are however no records of any production from these.

3.5.2 Resource potential

Future working specifically for ganister is unlikely though some production may be possible as a by-product of opencast coal working.

3.6 Brick Clay and Fireclay

3.6.1 Occurrence and history of exploitation

Bricks, tiles, refractory and sanitary products were formerly manufactured in the district from locally worked raw materials. Refractory bricks of various types and sanitary ware were made at Broughton Moor Brickworks [0536 3365]. According to Vol. 14 of the Special Reports on the Mineral Resources of Great Britain (HMSO, 1920A, p.12) the clay was obtained from the seatearth of the Fireclay Band Coal though Eastwood (1930, p.1260) states that 'clay shales from about the horizon of the White Metal Band' were used. Building Bricks were also produced from the seatearth clay beneath the Little Main Seam of Bertha Pit [0626 3336]. This clay is said to have been 'very oily' when mined and to have been allowed to weather for long periods before being used for brick making (Anon, 1920A). Some fireclay was formerly produced, together with ganister, from Branthwaite Colliery [059 253] (Anon, 1920A & B). The horizon from which this was obtained is not clear but may have been beneath the Sixquarters Seam.

Vol. 14 of the Special Reports on the Mineral Resources of Great Britain (Anon, 1920A, p.14) notes that a shale worked at outcrop near the old brickworks at Standing Stones near Broughton Moor produced, when mixed with fireclay, a blue brick used to floor sulphate of ammonia plants. The horizon of this shale was not specified. The site has now been removed during the working of Low Close Opencast Coal Site.

An old brick and tile works east of Branthwaite Edge [067 230] was supplied with clay from nearby pits. According to Eastwood et al. (1931, p.271) this was either a shale from 'near the Cleator Moor Coal Group' or from the glacial drift. The pits, the site of which cannot now be identified, were presumably long disused and degraded at the time of the last field survey in the 1920s.

It is likely that a number of seatearth clays in the Coal Measures could be suitable for the manufacture of fireclay refractories. A number of mudstones in both the Coal Measures and Hensingham Group may be suitable as raw materials for brick making. Whereas it is considered that working for these materials alone is unlikely, the extraction of suitable clay and mudstone during opencast coal working may be viable. Fireclays are understood to be produced as occasional by-products of opencast coal mining in Cumbria although the level of production is unknown.

Weathered Skiddaw Group mudstones in the Askham area, south Cumbria, are currently worked as a raw material for brick making. The Skiddaw Group rocks of the present district are almost certainly too indurated to be considered for such use.

Boulder clay or till, where comparatively stone-free, may provide suitable material for brick making. In this district much, if not all, of the boulder clay is almost certainly too stony for such use and there is no evidence that any has been worked. The boulder clay is unlikely ever to be considered a possible source of brick clay within this district.

3.6.2 Resource potential

A resumption of extraction of raw materials for brick, tile or refractory manufacture within the district is very unlikely except as a by-product of opencast coal working.

3.7 Cleaved Mudstone and Siltstone

3.7.1 Occurrence and history of exploitation

Cleaved mudstones and siltstones belonging to the Skiddaw Group crop out in the south-east of the district between Mockerkin and Lamplugh, although like the other solid formations they are mainly concealed beneath glacial deposits.

Small quarries in the Kirk Stile Formation at Mockerkin How [0994 2272] and in the Loweswater Formation on the hillside east of Lamplugh [0961 2114] have provided small quantities of grey cleaved mudstone and siltstone, apparently exclusively for local use as random building stone or for drystone walling.

The rock types present within the Skiddaw Group of this district have little appeal as building stone save for extremely local, mainly farm, use. The use of Skiddaw Group mudstones elsewhere in Cumbria for brick making is mentioned above in Section 3.6.

3.7.2 Resource potential

Whereas very considerable reserves of cleaved mudstone and siltstone are present it is extremely unlikely that they will attract any commercial interest in the foreseeable future.

3.8 Igneous Rock

3.8.1 Occurrence and history of exploitation

Igneous rocks of different types and different ages crop out in two parts of the district.

The Cockermouth Lavas, near the base of the Carboniferous succession crop out in the Derwent Valley north-east of Brigham. Except in the banks and bed of the river [0993 3113] these are all concealed beneath Quaternary deposits. The lavas comprise mainly olivine basalts, with both compact massive and amygdaloidal varieties present. No quarrying of Cockermouth Lavas has taken place in the district.

One intrusive igneous body is present in the district. This is the microdiorite intrusion in the Kirk Stile formation east of Eaglesfield. The intrusion crops out from the surrounding boulder clay as a steep-sided low rocky knoll. Although no contacts are exposed the body cannot occupy an outcrop of more than 0.6 ha. The rock at outcrop is a fine-grained pale grey to white microdiorite with closely spaced jointing. Dark brown ferruginous weathering is conspicuous, no doubt resulting from the breakdown of abundant disseminated pyrite seen in thin section of the rock. There is evidence of some very small-scale quarrying in the small outcrop.

3.8.2 Resource potential

Although very similar rocks are quarried elsewhere in Britain for roadstone and crushed rock aggregate, the Cockermouth Lavas of the present district have too limited an outcrop, are too heavily drift-covered and are too poorly situated to attract any commercial interest.

The microdiorite of the Eaglesfield intrusion has no appeal as a roadstone, an aggregate or a building stone and is unlikely ever to invite commercial interest.

3.9 Iron Ore: Hematite

3.9.1 Occurrence

The district includes the northern-most known deposits of the formerly important west Cumbrian hematite iron ore field. The main deposits of this field lie to the south of the district and are concentrated between Frizington and Egremont. Although records of iron mining date back over several centuries, the industry reached its peak in the latter half of the nineteenth and first half of the twentieth century. Large-scale mining ceased in the late 1970s but mining on a comparatively small scale continues today at one mine near Egremont. Unlike the coal mining industry no comprehensive history of west Cumbrian iron mining has yet been published. These hematite deposits together with local coal, gave rise to the iron and steel industry for which west Cumbria was long famous. Accurate production figures are not available but west Cumbria is known to have produced well in excess of 100 million tonnes of hematite ore containing on average between 50 and 60 per cent of metallic iron.

The majority of the hematite deposits (and the largest) occurred as replacements and vein-like bodies within the Lower Carboniferous Limestones. Some important but smaller deposits occurred as true fissure veins with the Lower Palaeozoic rocks, most notably the Skiddaw Group rocks, of the western Lake District. The form, mineralogical composition and possible origin of these is discussed in the Geology report. The most comprehensive description of the west Cumbrian hematite ore field is that by Smith (1924), written when several mines, including one in the present district, were still working.

Hematite has been worked at several places in the Lamplugh area. The sites of shafts and extent of the ore bodies, where known, are shown on Map 8.

The group of workings known as the Coronation Mine [075 201] near the Lamplugh Tip Inn, west-south-west of Lamplugh was the largest of the mines worked in the district, and is the only one for which plans have been traced. The ore occurred here as a series of irregular and vein-like bodies associated with several faults in the Fourth Limestone. These were up to 30 m in vertical thickness and around 90 m in breadth. Much of the ore was massive compact hematite, the best of which contained about 55 per cent metallic iron with 5–8 per cent silicon and 0.004–0.008 per cent phosphorus. In 1924, Coronation Mine was producing about 1000 tons of ore per week. Smith (1924) records outputs of 950 tons from Murton Pit in 1880, 380 tons from Whinnah Pit in 1883 and 17 060 tons from Coronation and Murton in 1913. The ore was taken from the mine by aerial ropeway to a loading bay [0648 2097] on the old railway south of the former Lamplugh Station.

Numerous boreholes have been sunk in search of hematite in the Crossgates area. Most were unsuccessful, although Smith records hard compact hematite and soft 'smit' in the Fourth Limestone in one hole.

Smith (1924, p.147) records that hematite was raised many years ago from a shallow shaft [0891 2070] about 250 m west-south-west of Lamplugh Church. The ore was found at the faulted contact of the limestone (probably the Fifth) and Skiddaw Group mudstone. According to Smith (1924) a boring approximately 150 m north-north-west of the shaft proved a total thickness of about 2 m of ore and 'spar' near the surface in the Fifth Limestone. Another borehole 90 m north-west of this found only 'gossany' limestone with hematite filling joints, also in the Fifth Limestone. BGS records indicate two shafts at this site although no records of the depths or details of the beds penetrated have been traced. Neither the date of working nor the quality and quantity of ore mined is known although the latter is likely to have been small. The extent of the workings is unknown but is unlikely to have been large.

Hematite is said by Smith (1924, p.148) to have been obtained from a shallow shaft, the site of which was then long obliterated, near Havercroft Cottage [0775 2203]. The exact site of the shaft, the horizon from which the ore was obtained, the extent of workings, the amount of ore raised and the date of working are all unknown.

Trials have been made for hematite on the north side of Crag Hills, west of Eaglesfield Crag. A small shaft is said to have been sunk into the Fourth Limestone. No records of the sinking have been found but it is likely to have been very shallow. A small depression in the field [0975 2747] may mark the site of the shaft. Exploration boreholes were sunk in the Fourth Limestone in the fields up to 250 m north of the trial shaft. Detailed records have apparently not been preserved, although a manuscript note by E E L Dixon made at the time of the last survey (1921–24) indicates 0.18 and 0.5 m of ore at depths of about 13 m in two boreholes. The date of these trials is unknown.

3.9.3 Resource potential

No reserves of hematite are known at any of the previously worked locations and there are no grounds for expecting further reserves to exist. Any resumption of exploration for hematite ore within this district is extremely unlikely.

3.10 Iron Ore: Clay Ironstone

3.10.1 Occurrence and history of exploitation

Clay ironstones or siderite mudstones are common as thin beds or as beds of nodules within mudstones of the Coal Measures. Within the present district such ironstones have been worked from adits and shafts south-east of Branthwaite. Eastwood et al. (1931, p.190) suggested that these ironstones occurred at about the horizon of Yard seam. The present survey indicates that a horizon a little above the Harrington Four Foot seam is more likely. Small heaps of mudstone spoil, with a little clay ironstone, mark the sites of adits between [0595 2470] and [0613 2455], and the sites of shafts east of Totter Gill between [0646 2394] and [0675 2380].

The ore is likely to have been won by pillar and stall mining. No plans of the workings have been traced, neither have any production figures been found. The workings are however likely to have been of comparatively small extent and the tonnage produced is likely to have been small.

3.10.2 Resource potential

Although no analyses are available for clay ironstones from this district, ores of this type typically contain up to 25 per cent metallic iron (Cantrill 1920, p.98). There is little likelihood of such low grade ores attracting commercial interest in the future even as a by-product of opencast coal mining.

3.11 Sand and Gravel

3.11.1 Occurrence and history of exploitation

Comparatively small deposits of sand and gravel are present within the district, although none is currently worked except intermittently for local farm use. Much of the known sand and gravel is present as glacial sand and gravel mapped as glaciofluvial deposits on the Drift Geology Map (Map 2) and shown also on Map 8.

Pits from which sand and gravel have been extracted are shown on Map 8. Almost all of these are within outcrops of glacial sand and gravel though in places e.g. at a very small pit [0960 3162] 500 m east of Papcastle Station, a small lens of sand and gravel within till was worked. Most of the district's sand and gravel pits are very small and were presumably worked to supply local, and probably intermittent, demands. A small pit [0686 2147] west of Woodend Cottages currently provides very small amounts of sand and gravel for the local area. All of the district's sand and gravel pits are much degraded and overgrown and good sections through the worked deposits are few. Where seen the sand and gravel consists of fine- to coarse-grained, moderately- to well-sorted gravel with some coarse sand in places: crude bedding is seen locally. The deposits are composed almost entirely of pebbles of locally derived Carboniferous and Lake District rock types.

3.11.2 Resource potential

No systematic assessment of thickness or quality of any of the district's sand and gravel deposits has been undertaken within this study. However the positions of boreholes which proved more than 1 m of sand and gravel with an overburden ratio of up to 3:1 are indicated on Map 8. The extent of the exposed outcrop is shown on Map 8. The most extensive spreads of sand and gravel occur in the Derwent and Marron valleys. Concealed extensions of some of these may be present within the boulder clay or till and other concealed deposits may also exist within the glacial sequence. Many of the mapped outcrops of glacial sand and gravel are likely to be too thin to be attractive prospects for working. Some of the larger outcrops may be worth investigating, although large scale sand and gravel working is unlikely to be possible in this district. Some deposits, which might otherwise be economically unattractive, may be recoverable as part of the overburden stripping regime in opencast coal extraction.

3.12 Peat

3.12.1 Occurrence

Small areas of peat have been mapped in several parts of the district and in addition beds of peat or peaty clay are locally present within the alluvium. Little is known of these deposits in detail but none is likely to exceed 1.5 m in thickness (see Geology report). There is no evidence that any of the district's peat has ever been worked either as fuel or as a soil conditioner.

3.12.2 Resource potential

Although lowland peat of this sort is worked, mainly for horticultural use, in other parts of Britain, e.g. the Solway coast and Somerset, the deposits of the present district are too small to be of commercial interest.

3.13 Colliery spoil

3.13.1 Occurrence

Colliery spoil, usually composed of a mixture of shale and sandstone, provides a valuable source of fill material in many coalfields. Where spontaneous combustion of organic-rich, commonly pyritic, shale has occurred in spoil heaps a red brick-like shale results. This too constitutes a valuable resource in many coalfields but none of the spoil heaps in the present district appear to have suffered any significant degree of such combustion.

3.13.2 Resource potential

Within the present district colliery spoil heaps are all comparatively small and contain insufficient material to provide for anything but local use as fill.

3.14 Glacial erratics

3.14.1 Occurrence and history of exploitation

The boulder clay or till of the district contains abundant cobbles and boulders of a variety of local and Lake District rock types. Clearance of these from many fields has provided material for dry stone walling as well as for many older stone buildings.

3.14.2 Resource potential

The erratic cobbles and boulders of the district have only very limited potential for local use in repairing dry stone walls.

3.15 Surface and groundwater

3.15.1 Occurrence and history of exploitation

This district lies mainly within Hydrometric Area 75, for which the water resources are administered by the North West Regional Office of the National Rivers Authority. The mean annual rainfall varies somewhat across the district, but is generally between 1400 and 1800 mm. The drainage is mainly via the river Derwent and its southern tributary the river Marron. The contribution of groundwater to river flow is not large, and the base flow index of both rivers is of the order 0.48, while many of the contributory streams may have an index of 0.30 or less. This is well illustrated by the measured flows at the Camerton gauging station [038 305] on the river Derwent where the winter flood flows may exceed 180 cubic metres per second (cumecs) against a mean flow of 25 cumecs and a recorded minimum of 2.04 cumecs in a 30 year record.

Good aquifers are not present in this district. The majority of water supplies, other than from surface sources, consist of springs and shallow shafts, but the licensed abstraction from such sources rarely exceeds 100 cubic metres per day (m^3/d), and is usually much less. Flows from springs tend to decrease (or even to fail) during prolonged dry weather, and the levels in wells tend to fall in the same way. There are no records of water boreholes having been constructed within the district.

In the Coal Measures, groundwater is generally confined to the sandstone and grit horizons. However, these beds are usually well cemented, and the groundwater is contained within, and flows through, fissures. On the whole the fissures are poorly developed and yields to boreholes are unlikely to be great, probably less than 100 to 200 m^3/d at best. With increasing depth, the fissures tend to be fewer and tighter, and drilling a borehole to depths of more than 50 m is not usually worthwhile. At a site to the west of the district, the National Coal Board obtained a supply of over 1000 m^3/d from a large diameter shaft of some 50 m in depth, but much of the yield appears to have come from superficial deposits rather than from the Coal Measure rocks. Hydrogeologically the Namurian strata are very similar to those of the Coal Measures.

The more extensive sandstones of the Carboniferous seem generally to be too well cemented to form useful aquifers. Sufficient fissuring may be developed in the weathered zone to permit small yields to wells, probably less than 100 m^3/d for the most part. This zone is unlikely to extend downwards more than 30 or 40 m beneath the ground surface. On the higher ground, the weathered zone tends to drain rapidly, and little groundwater may remain in storage to be exploited by wells. Weathered zone groundwater often lies close to the ground surface, and is in consequence vulnerable to pollution from surface sources such as farmyards and middens.

The Chief Limestone Group forms the only potentially useful aquifer in this district. Groundwater is effectively restricted to the limestone horizons. The matrix of the rock is essentially watertight, and groundwater is contained within, and flows through, fissure systems. The fissures may be large in size, and near-karstic conditions may be present locally. However, the fissures are not generally numerous and are distributed at random through the rock. Boreholes that fail to intersect such fissures beneath the water table are usually 'dry', collecting little more than seepage, but substantial yields may be obtained where one or more fissures are cut. Where the limestone outcrop occupies the higher ground, the water table may be at a considerable depth, and, more importantly, the natural drainage can be very rapid and the amount of groundwater retained in storage consequently small. Much of the limestone outcrop may be susceptible to pollution from surface sources. This should be taken into account when considering the use of abandoned limestone quarries as landfill sites.

Groundwater in the Ordovician strata is likely to be confined to the weathered zone within 30 or 40 m of the ground surface. Sufficient fissuring may be developed to permit shallow boreholes or excavated shafts to obtain small yields of groundwater sufficient for small requirements of 20 to 30 m^3/d, but even these may fail in dry weather. Springs issuing from these strata are usually small and often impersistent.

Among the superficial deposits, there is perhaps some potential for supply from the sands and gravels of the glacial sequence. These may not always be free of a substantial clay or silt fraction, in which case yields to boreholes may be limited. Nonetheless, shallow shafts often form the basis of supply for smallholdings and dwelling places. The water is not always of good quality and is usually vulnerable to pollution from surface sources.

The groundwater obtained from shallow shafts and boreholes in the Namurian and Westphalian rocks of the district should, for the most part, be soft, with a total hardness of less than 200 mg/l (as $CaCO_3$), largely carbonate hardness. The chloride ion concentration should be less than 40 mg/l; values in excess of this are likely to be an indication of pollution. High concentrations of iron are occasionally found in sand and gravel deposits in particular, sometimes in excess of 5 mg/l. Water derived from the limestone outcrop is likely to be hard.

3.15.2 Resource potential

Whereas there may be limited potential for exploiting surface water there is little incentive for this, bearing in mind the location of the area adjacent to the abundant supplies in the neighbouring Lake District from which most of the districts' water supply is currently obtained.

Similarly any interest in developing significant sources of groundwater is unlikely especially in view of the likely contamination of potential aquifers by mining, quarrying and land filling.

3.16 Waste disposal

The district includes a small number of waste disposal sites licensed by Cumbria County Council. The sites of these are shown on Map 6. The location of these together with their license number

Table 6 Landfill sites within the district

SITE NAME	CUMBRIA COUNTY COUNCIL LICENCE NUMBER	CLASS OF WASTE	STATUS
Broughton Moor	R3	Domestic, trade and industrial	closed
Linefoot Farm	R47	Excavation material and general inert waste	closed
Broughton Craggs	R15	Domestic, trade and industrial Inert waste	closed active
Broughton Cross	None	Excavated material	closed
Kirkcross Quarry	67	Inert waste	active
Limekiln Quarry	49 and 107	Building rubble and surplus excavated material	closed
Bridgefoot Linefitts	None	Inert waste	closed
Land SE of A66	None	Inert waste	closed
Hotchberry Quarry	37	Excavated earth and clay sub-soil. Demolition rubble. Bark and Quarry waste.	active

and the category of waste to which the current license applies is shown in Table 6.

Small quarries throughout the area may offer some potential as landfill sites for local use. More interest is likely to focus on large excavations made for extraction of coal or limestone. Such excavations could provide a capacity for disposal of large volumes of waste. However the employment of such sites for landfill, particularly those in limestone, would require careful consideration after detailed investigations of the geological and hydrogeological characteristics of the site. Alternative uses, including conservation and amenity potential, should also be studied.

3.17 **Conservation**

There is today an increasing awareness of the need to conserve important sites of geological or natural history interest. Sites of major national significance are scheduled by the English Nature (formerly the Nature Conservancy Council) as Sites of Special Scientific Interest (SSSIs). No sites with SSSI status for their geological interest are present within the district. However English Nature have recently introduced a scheme aimed at conserving sites which although not appropriate as SSSIs are nevertheless of value primarily for earth science teaching. These Regionally Important Geological/Geomorphological Sites (RIGS) are currently being designated throughout England. Several abandoned quarries and a number of natural outcrops within the district may warrant such designation. Potential sites include the Orebank Sandstone outcrops in Broughton Crags Quarry and the Hensingham Grit in the abandoned quarries at Brigham. The designation of sites is likely to be handled jointly by English Nature and local geological groups such as the Cumberland Geological Society and the Yorkshire Geological Society. Any proposed developments at such sites should take into account this potential conservation interest.

4 GEOLOGICAL CONSTRAINTS FOR CONSIDERATION IN LAND-USE PLANNING

4.1 Introduction

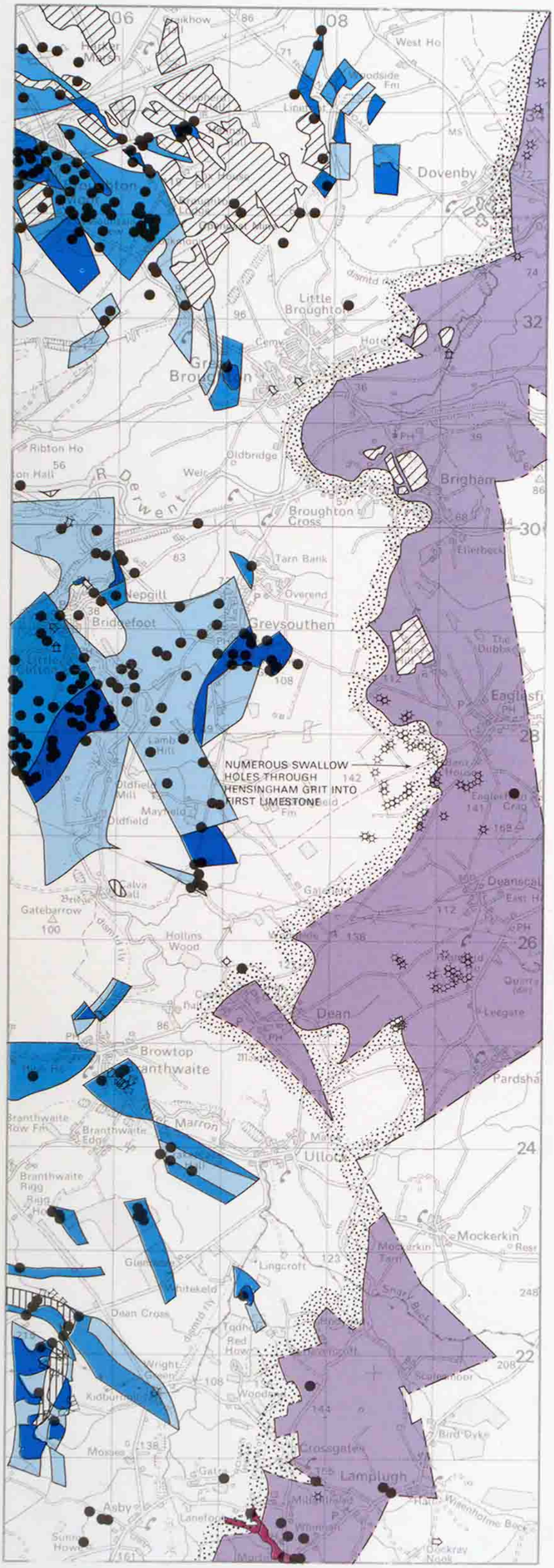
This chapter outlines the influence exerted on future planning and development by geologically related factors, including the legacy of mining activity in the area or by natural geological phenomena e.g. Karstic processes or seismicity.

Table 7 provides a guide to the 1:25 000 maps which should be consulted when reading this section.

The problems associated with these geologically related activities fall into two categories i) stability and ii) contamination. Both categories of problems can arise due to either natural processes or man's activities. The same process can also give rise to both stability and contamination problems e.g. a quarry backfilled with domestic waste could lead to stability problems related to differential compaction and contamination problems due to leachates. Similarly effects such as methane generation can either occur naturally or can be acceler-

Table 7 Guide to 1:25 000 maps which should be consulted when reading Section 4.

		1:25 000 SCALE THEMATIC MAP								
		1. SOLID GEOLOGY	2. DRIFT GEOLOGY	3. ROCKHEAD ELEVATION	4. DRIFT THICKNESS	5. GROUND STABILITY	6. MADE AND DISTURBED GROUND	7. BOREHOLE & SHAFT SITES	8. MINERAL RESOURCES	9. GEOLOGICAL FACTORS FOR CONSIDERATION IN LAND-USE PLANNING
SECTION IN THIS REPORT	COAL MINING	×		×	×	×	×	×	×	×
	IRON ORE MINING (HEMATITE)	×				×	×	×	×	×
	GASES	×				×	×	×		×
	KARST FEATURES	×	×	×	×	×			×	×
	MADE AND DISTURBED GROUND		×	×	×	×	×		×	×
	SEISMICITY					×				×
	MINERAL RESOURCES	×	×	×	×		×	×	×	×
	LANDSLIP	×	×			×				×



KEY

Landslip - refer to the report Geology and land-use planning: Great Broughton - Lamplugh. Part 2 for a discussion of landslips and possible contributory factors.

COAL

Workings recorded on plans

Some evidence of mining from surface features or borehole data, no plans available

Local workings possible (seam known to have been worked elsewhere in the district)

Workings probably absent within 30 metres of surface

Worked-out opencast coal seam area (other shallow mining may exist below opencast site)

IRON ORE

Extent of workings as recorded on plans. No estimate has been made of depth from which collapse of Iron ore workings may propagate to the surface. It is likely that collapse of these workings which may be cavities of considerable vertical height, could propagate to surface through many tens of metres of cover

Limestone

Base of beds which overlie Chief Limestone Group

Faulted boundary between Chief Limestone Group and overlying beds

Ground disturbance related to limestone dissolution may occur on shaded side of boundary. No information is available concerning the depth from which limestone dissolution features may propagate to the present ground surface. The presence of ground conditions which may lead to problems can only be determined by a site investigation.

Basal contact of Chief Limestone Group

Faulted boundary of Carboniferous rocks

Pit or mine shaft, abandoned

Pit or mine shaft, abandoned, site uncertain

Adit or minemouth, abandoned, showing direction of entry

Adit or mine mouth, abandoned, direction of entry unknown

Swallow hole

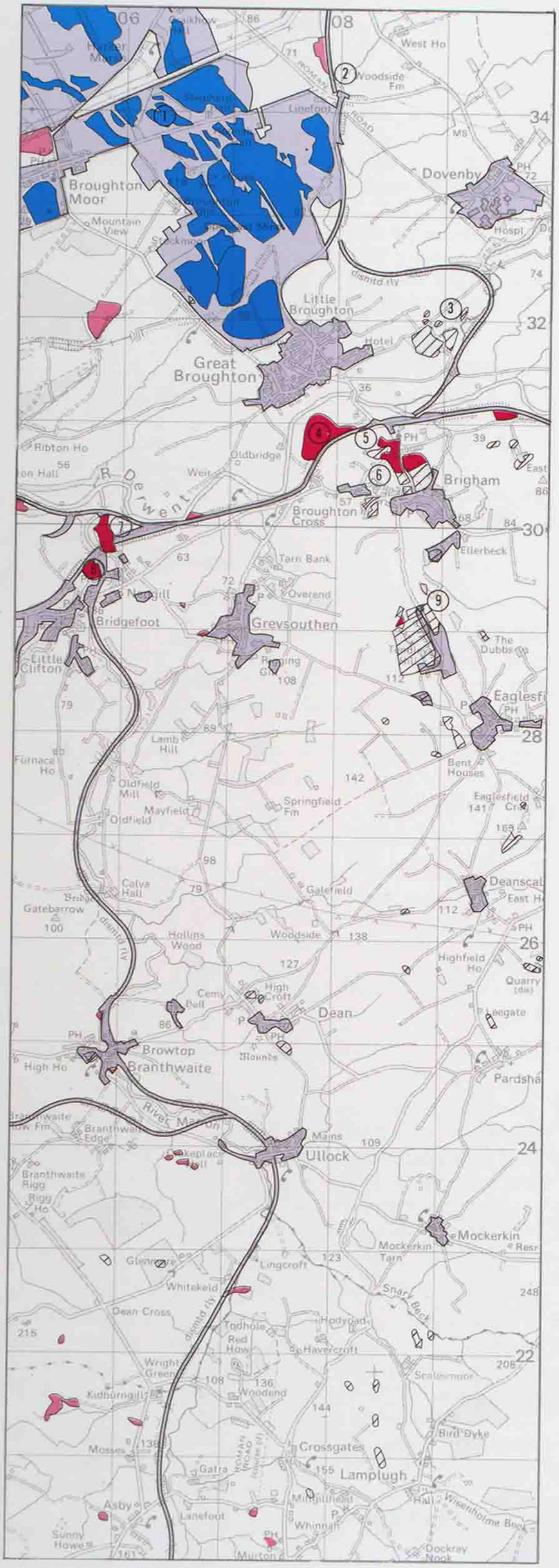
This figure is a simplified portrayal of 1:25 000 scale map 5 which should be consulted for detailed information

Scale

0 1 2 3

kilometres

Figure 10 Ground stablility map



KEY

Worked-out opencast coal seam area (generally backfilled with overburden material)

Miscellaneous waste: including domestic, agricultural, industrial, building and quarry waste

Colliery and iron ore mine waste: areas composed predominantly of colliery and iron ore mine spoil

Landscaped Ground: areas where the original surface has been extensively disturbed and/or remodelled principally by building and/or surface mining

Approximate area of excavation in former quarry or pit, excluding opencast coal seam areas

(6) Waste disposal site: see list below

SITE NUMBER AND NAME	LICENCE NUMBER	CLASSES OF WASTE	STATUS
1 Broughton Moor	R3	Domestic Trade and Industrial	Closed
2 Linefoot Farm	R47	Excavation material and General Inert waste	Closed
3 Broughton Craggs	R15	Domestic Refuse and Trade and Industrial Waste	Closed
		Inert Waste	Active
4 Broughton Cross	None	Excavated Material	Closed
5 Kirkcross Quarry	67	Inert Material	Active
6 Limekiln Quarry	49 & 107	Building rubble and Surplus excavated material	Closed
7 Bridgefoot Linefitts	None	Inert	Closed
8 Land South East of A66	None	Inert	Closed
9 Hotchberry Quarry	37	Excavated earth and clay Subsoil Demolition Rubble Bark and Quarry Waste	Active

This figure is a simplified portrayal of 1:25 000 scale map 6 which should be consulted for detailed information

Scale

0 1 2 3

kilometres

Figure 11 Made and disturbed ground

ated or accentuated due to man's activity. Thus no simple division of processes and resulting problems can be made.

The factors considered in the initial five sections of this chapter, respectively shallow coal mining, iron ore mining, karst features, landslip and made and disturbed ground relate to areas which have been delineated on the thematic maps. The first four categories are represented on Map 5 and Figure 10 while the fifth category is shown on Map 6 and Figure 11. The sections describe the nature of each category and the problems associated with development of areas affected by them.

The problem of gases is covered in a separate section, although their development is intimately connected with the processes discussed in the preceding sections. The links between coal and iron ore mining, karst, made ground and the occurrence of gases has been highlighted in the report and the reader is advised to consult all of the relevant sections.

The final two sections respectively describe the seismic potential of the area and the potential for sterilisation of resources. This latter section relates largely to Section 3 to which the reader is referred.

Map 9 and Figure 12 present a graphical summary which highlights specific elements from the individual thematic maps which are particularly relevant to planning and development. This compilation allows quick identification of the principal areas where difficulties may exist or problems are less likely. Since only selected aspects have been abstracted, this map is a general guide to the more detailed individual thematic maps which also should be consulted. **The need for properly designed and executed site-specific investigation cannot be overstated.**

4.2 Coal Mining

The history of coal mining in west Cumbria has been outlined briefly on in Section 3.2. This history of underground working gives rise to two questions prior to the development of any area:

a. Has the area been undermined?
b. At what depth and by what methods has this mining taken place?

The type of collapse features which develop vary depending on the mining methods which were used. The different mining methods are outlined in the first part of this section and the type of collapse which may occur due to the different mining methods is then described.Areas liable to surface disturbance due to shallow coal mining are shown on Map 5 and this map should be read in conjunction with this section of the report.

4.2.1 Coal mining methods

Bell Pits

A shaft, usually 1 m in diameter, was sunk through the overlying strata to the coal at a maximum depth of approximately 15 m. The coal was worked in a circular area centred around the shaft. The area worked may be up to 20 m in diameter, the bell pit being abandoned when the unsupported roof became unstable. The process may have been repeated in a number of adjacent pits aligned parallel to the outcrop of the coal seam. This method recovered a high percentage of the seam but was limited in extent to near the surface outcrop.

Pillar and Stall

The seam was worked by a network of roadways which intersected at right angles with unmined pillars of coal being left to support the roof. Initial extraction rates were commonly increased by removing the pillars on retreating. Pillar and stall workings have been uncovered in west Cumbria during opencast activity (e.g. Oughterside Opencast site (Young and Armstrong, 1989)).

Shortwall or Panel method

In this system coal was extracted from a broad face, the roof being supported by wooden props. The void was subsequently filled with mining waste allowing gradual settlement of the roof. This method resulted in recovery rates of up to 80 per cent. Shortwall working may have occurred in conjunction with, or as a reworking of, areas of pillar and stall.

Longwall method

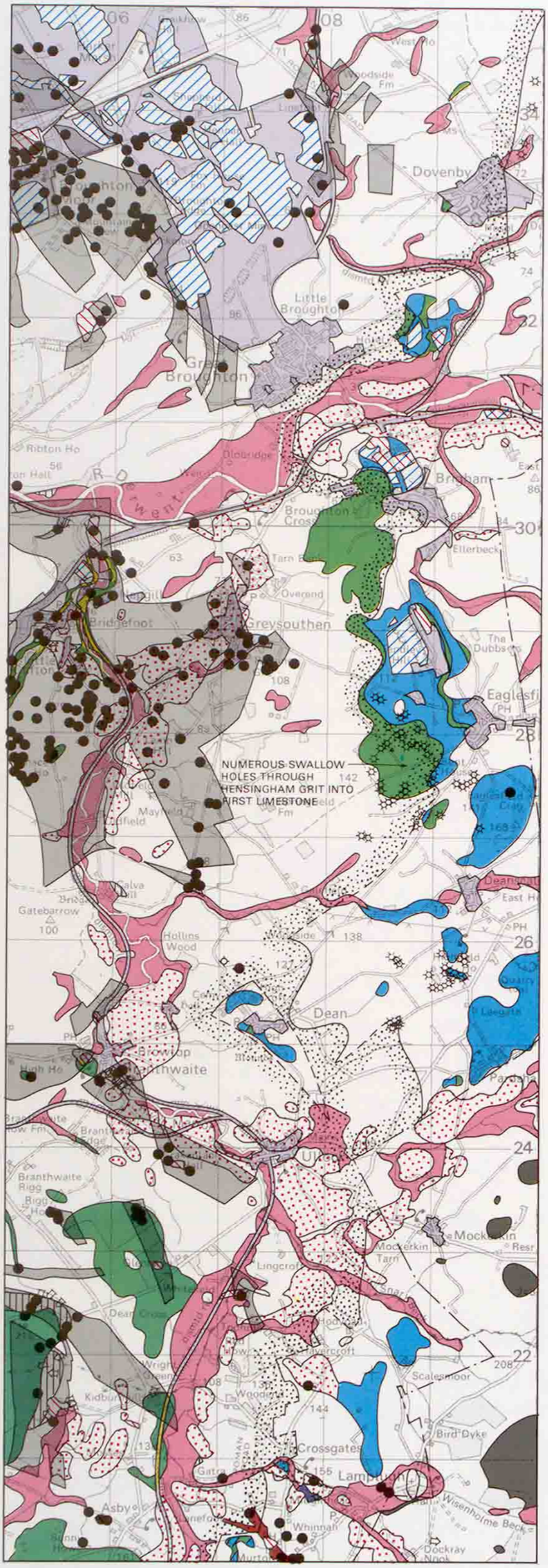
Longwall mining is the mechanised method of extraction currently used in most British Coal deep mines. Two parallel headings, typically about 200 m apart, are driven from a main development road. The coal is extracted from between the headings, the roof being allowed to collapse behind the face as it is driven back towards the development road.

4.2.2 Stability Problems caused by Coal Mining

This section will outline the possible collapse features which may be associated with different mining methods. It should be noted that due to the variable nature of both lithologies and extent of extraction no account can be comprehensive. This problem is compounded by the fact that many early workings may not be documented or the plans that exist may be inaccurate.

Bell Pits (and shallow drifts)

The sites of bell pits are unlikely to have been recorded. No bell pits were examined during the present study and therefore the nature of their backfill and the state of collapse is unclear. It is known from other studies that bell pits were usually poorly backfilled and thus the possibility for future collapse exists. Bell pits (and shallow drifts) are more likely to occur within the 30 m areas shown on Map 5.



KEY

LAND STABILITY

		EXPLANATION
	Landslip	Areas of unstable ground subject to recent downslope movement (See Map 5 Ground Stability)
	Alluvial and Lacustrine deposits	May consist of generally low strength, medium to high compressibility silts and clays and water-bearing loose sands and gravels. May contain beds of peat. Foundation problems likely.
	Quarry, pit or opencast infill	Settlement and compaction of fill expected. Possible problems associated with fill material of variable bearing capacity and presence of hazardous or methane generating components (See Map 6 Made and Disturbed Ground).
	Artificial deposits on natural landscape	Highly variable in composition and engineering properties. Possibility of hazardous or methane generating components (See Map 6 Made and Disturbed Ground).
	Landscaped ground	Engineering properties may have been altered (See Map 6 Made and Disturbed Ground).
	Coal or Ironstone workings likely to be present within 30m of ground surface	Potential cause of subsidence. Where available detailed mine plans should always be consulted. Shallow mining may exist outside these zones. (See Map 5 Ground Stability).
	Iron ore workings, extent proved from mine plans	
☼	Swallow hole	Possibility of collapse. Swallow holes indicate areas of potential subsidence. Swallow holes, other than those shown may exist or may develop. (See Map 5 Ground Stability).
●	Pit or mine shaft, abandoned	Possibility of collapse, escape of gas or accidental entry. State of adit or shaft must be investigated and if necessary, made safe prior to development. (See Map 7 Boreholes, Shafts and Adits and Map 8 Mineral Resources and Extraction).
◇	Pit or mine shaft, abandoned, site uncertain	
	Adit or minemouth, abandoned, showing direction of entry	
	Adit or minemouth, abandoned, direction of entry unknown	

NOTE: Land outside the above areas is not known to be subject to significant physical constraints but still requires proper site investigation before development.

MINERAL RESOURCES AT SURFACE

	Sand and gravel deposits at surface	Should be assessed prior to any extensive development to avoid sterilization of potential resource. (See Map 8 Mineral Resources and Extraction).
	Sandstone at surface	
	Cleaved mudstone at surface	
	Limestone at surface	
	Base of beds which overlie Chief Limestone Group	Ground disturbance related to limestone dissolution may occur on shaded side of boundary. No information is available concerning the depth from which limestone dissolution features may propagate to the present ground surface. The presence of ground conditions which may lead to problems can only be determined by a site investigation.
	Faulted boundary between Chief Limestone Group and overlying beds	
— — — —	Basal contact of Chief Limestone Group	
—·—·—	Faulted boundary of Carboniferous rocks	

This figure is a simplified portrayal of 1:25 000 scale map 9 which should be consulted for detailed information

Figure 12 Geological factors for consideration in land-use planning

Pillar and Stall

Pillar and stall workings have been identified on mine plans from the area. Pillar and stall workings create particular problems in that they may not collapse after working has ceased, particularly at shallow levels where pressure due to the overlying strata may be low.

The parameters affecting collapse in pillar and stall workings have been examined by a number of workers (Pigott and Eynon 1978, Garrard and Taylor 1988).

Three principal methods of collapse of pillar and stall workings were described by Pigott and Eynon (1978):

A. Collapse of roof beds spanning adjacent pillars.
B. Pillar failure.
C. Squeeze of floor or roof strata.

Collapse of roof beds spanning adjacent pillars Collapse of roof beds overlying the worked void is the principal instability problem. Pigott and Eynon (1978) proposed that collapse into old workings could affect overlying strata a distance equivalent to 10 × the void height above the workings. Garrard and Taylor (1988) proposed that the width of the working was the main control and that it could affect a distance of 2.68 × the width of the void above working.

Two principal factors which limit the upward propagation of collapse are proposed:

A. Bulking
B. Arching.

Bulking occurs where roof debris which has collapsed into the void will eventually support the roof and thus halt further collapse. The height at which bulking will stop roof collapse will depend on both the volume of the void and the change in volume of the collapsed material from its intact to its loose state. The nature of the overlying strata together with any fracture/joint pattern developed will influence this latter factor. The theoretical height at which bulking should arrest roof collapse may be exceeded if roof debris is extruded along roadways into other parts of the workings. This process may be enhanced by the movement of water through the workings.

Bridging is the process by which a competent unit within the roof rocks may arrest the upward migration of a void. Sandstones, particularly if they are some distance form the immediate roof of the working, are an effective bridging unit. Garrard and Taylor (1988) found that interbedded units show the greatest height of collapse/width of worked beds ratio. The same authors noted that the width of worked stalls increased where a sandstone formed the roof of the working. Therefore if the collapse height is related to the width of the working, old workings roofed by sandstones should collapse to the highest levels.

Pillar Failure The stability of pillars will depend mainly on their geometry. It has been found that at shallow depths the size (and hence strength) of the pillars normally left during mining is sufficient to support the overlying strata. However, where pillar size is small, or pillars have been weakened e.g. by chemical attack, failure may occur. This may transfer loads onto other pillars which may in turn fail.

Pillar collapse may be induced by surface loading. Care should be taken in areas of known shallow workings when the laying of building foundations involves high concentrated loads.

Squeeze of roof or floor strata The pillar may 'punch' into under- or overlying 'soft' rocks such as seatearths producing irregular subsidence at the surface. This form of failure commonly occurs when mines become flooded subsequent to abandonment.

The problems associated with pillar and stall workings require that comprehensive site investigations must be carried out prior to development in an area of known shallow mining. Care should be taken when designing a drilling programme as too few holes or those drilled on a regular grid pattern may only find pillars and miss the voids.

The problem of identifying collapsed voids in boreholes should also be recognised. The former presence of a coal may only be indicated by a thin layer of coal dust and/or weathering of a seatearth when the roof and floor rocks have been compressed together with only slight disturbance.

Longwall mining

Longwall mining involves almost immediate collapse of the roof rocks into the void created by extraction. As with other mining methods the surface effect of this mode of extraction is dependent on the depth, thickness and width of the workings as well as the volume of material backfilled into the cavity. Subsidence is normally complete within a year of mining, some residual subsidence occurring over the next few years. The development of tension fissures at the ground surface above collapsed longwall mining were described by Culshaw and Waltham (1987). Thin fissures, not more than 20 cm wide, were developed in competent sandstone and limestone units. However, these fissures led to the development of wider soil sinkholes and reactivation of landslip fissures.

Shafts and adits

Shafts occur throughout the area, and are shown on Maps 1, 5, and 8. Shafts can have a variety of cross sections including circular, oval, square, rectangular and polygonal. Shaft diameter has increased from approximately 2 m in the earliest workings to present day British Coal standards of 6.1 m and 7.3 m. Shafts are normally lined, originally with wood and later by uncemented bricks and stones. Metal linings and more recently concrete lining were also employed.

Shafts, especially deep shafts, have normally only been partially backfilled. Commonly a staging was built across the shaft, a short distance from the surface, and the shaft above the staging was filled. The nature of the fill varied considerably. In some cases the shaft lining was removed from above the level of the staging. The lining may decay leading to subsequent shaft collapse. It should be noted that subsidence related to shaft collapse propagates to the surface in a conical form. Subsidence will therefore affect an area centred on the shaft.

Adits are tunnels driven into coal seams to provide both access and drainage. Adits have a diameter of up to 3 m: diameters of 1 m are found in some older workings.

Frequently only the mine entrances were backfilled, leaving a tunnel void which may have suffered only partial collapse.

The treatment of disused coalmine shafts and adits is discussed in a National Coal Board publication (NCB 1982), and of shafts and adits, more generally by Freeman Fox Ltd (1988).

4.3 **Iron ore mining**

4.3.1 Introduction

As discussed in Sections 3.9 and 3.10 two types of iron ore were formerly mined within the district. The position of shafts and extent of known underground workings for iron ore is shown on Map 5 and Figure 10. The potential for underground workings to exist should be taken into account when planning any development within an area of known iron ore mining. As the full extent of workings is unknown no area of potential instability can be delimited.

Clay ironstone, present as nodules and bands within mudstones of the Coal Measures, was mined underground principally in the Branthwaite area. The gross form of these deposits and their extraction closely resemble those of coal seams. Problems related to ground previously mined for these ores are essentially the same as those for coal mining and thus the reader is referred to the previous section for further information on potential stability problems.

The deposits of hematite iron ore present in the south of the district form part of the formerly important west Cumbria iron ore field. The origin and form of these deposits has been described in some detail in the Geology report and discussed in outline above in Section 3.9, together with brief notes on the history of their mining.

The hematite ore bodies occur as large irregular replacements and vein-like bodies within the thick limestone units of the Chief Limestone Group. The ore bodies are thus quite unlike bedded deposits such as coal seams or sedimentary ironstones. Markedly different mining techniques have been used to develop and extract them and the problems associated with abandoned workings in them are therefore different.

The precise details of the mining method employed in a hematite orebody varied to suit the geometry of that deposit and in many cases rather different techniques were used in different parts of the same deposit.

In the replacement orebodies found in the district the normal practice for ore extraction could be regarded as a modified form of pillar and staff working. The procedure adopted was to work the orebody from the top downwards. From the working shafts cross-cut levels were driven into the orebody. As the extent of the body was determined in this way ore was removed as a series of slices leaving pillars or middlings for support. As the extraction continued the pillars were themselves removed or robbed. In some hematite mines the cover rocks collapsed as downward extraction proceeded. However in many, or perhaps most, instances this was not the case and worked-out orebodies were left as open, unsupported voids. In the massive and commonly relatively competent beds of limestone these workings may remain as voids for many years after the cessation of mining. Most will lie beneath the water table and will be flooded. Eventual failure of the walls and roof of the robbed orebodies inevitably occurs, although the timing and the size of any individual episode of collapse will be dependent on a large and complex number of factors.

4.3.2 Stability problems related to iron ore mining

We are not aware of any work done on the stability of ground above and surrounding these large Cumbrian orebodies. However work on the collapse of large abandoned underground limestone workings in the Dudley area of the West Midlands provides perhaps the best British analogy. (Braithwaite and Seago, 1988, Forster, 1988, Richards and Miller, 1988 and Longworth, 1988) and the following summary may be useful in this context. Mining here was by the pillar and stall method, with up to 90 per cent extraction. The beds worked were up to 7.3 m thick. Roof collapse was largely controlled by the clay filled joint pattern. Slabbing from pillars also followed this joint pattern. The strong control of jointing meant that roof-falls tend to occur around existing debris piles. Moreover the size of the roof-falls was found to be dependent on rock type with more resistant units producing larger falls but in smaller numbers.

At Castle Fields the potential for upward propagation of a void depended on a number of factors. The strength of the roof beds clearly plays an important role, with limestone forming more competent roof rocks than the interlayered shale units. The area which can remain unsupported between pillars will vary depending on the competence of the roof rocks and the inter-bed cohesion between the void roof and the overlying beds. Horizontal stresses may exert a 'clamping' effect on the unsupported roof, though the 'clamping' may be outweighed by the vertical stress exerted by the weight of strata overlying the void.

As mentioned earlier, jointing was found to be the main control on roof and wall collapse. Not only is the orientation and distribution of the joints important but also the frictional and deformational properties of the joint surfaces or their infilling material. These latter properties may be affected by water influx either due to hydrostatic pressure expanding the joints or reaction softening of the infill material.

As roof and wall collapse takes place 'building' by the roof debris may in fact fill the void and stop void migration. The effectiveness of this process will depend on the relative size of the void with respect to the volume of overlying strata.

Evidence for large scale collapse into hematite workings in the present district is rather limited. The largest hematite workings known in the district are those of Lamplugh Mine but these were far from large compared with others elsewhere in west Cumbria. Evidence for large scale collapse into the workings in the present district is limited but spectacular surface collapses into abandoned hematite workings are common in the orefield a short distance to the south of the district. In several instances collapses are continuing to propagate up to surface through perhaps as much as 200 to 300 m of cover rocks many years after the end of mining. Control of such collapse would be extremely costly even if it were regarded as feasible.

No reliable means are known for determining the extent of collapse either above or adjacent to these voids and determining when such collapse may be considered complete is best regarded as impossible. In any event the collapsed ground is likely to contain numerous smaller voids between failed blocks and cannot realistically be regarded as stable without extremely costly remedial measures. The safest policy known at present is to determine, as accurately as possible from documentary sources, and, if necessary, by site investigations, the known extent of the workings.

4.4 Karst

4.4.1 Introduction

Geomorphological features characteristic of country consisting predominantly of bedrock with a high degree of solubility in natural groundwater are known collectively by the word 'karst'. In common with most areas of Lower Carboniferous Limestone in Britain the limestone outcrops in the eastern part of this district exhibit a number of typical karst features.

Perhaps the most conspicuous of these karst features are the numerous swallow holes or dolines. Swallow holes are developed on the outcrops of most of the district's limestones but are present, or at least are recognisable, only in certain areas.

Whereas most swallow holes occur on outcrops of bare limestone, or on limestone with only a comparatively thin cover of superficial deposits, they may locally penetrate for a considerable distance upwards into overlying strata.

For a more detailed description of these features reference should be made to Section 12.11 of the Geology report.

The position of mapped karst features, such as swallow holes is shown on Map 5 and Figure 10, together with the extent of the limestone outcrop. It should be noted that swallow holes have been recorded to the west of Eaglesfield in areas underlain by sandstone of the Hensingham Grit. These features are interpreted as representing propagation of cavities developed within the limestones through the overlying sandstone units. Thus surface collapse due to limestone dissolution is not restricted to areas where limestone either crops out or directly underlies the drift. Map 5 indicates the areas which are underlain by limestone irrespective of the depth at which the limestone occurs. No attempt has been made to delimit a depth from which limestone cavities will propagate to the surface. The factors which determine whether a limestone cavity propagates to the surface are discussed in relation to iron ore mining (Section 4.3) and the reader is advised to refer to this section. The reader is referred to Jennings (1985) for a more complete discussion of karst processes and geomorphology.

Solution by carbonic acid in rainwater plays an important role in karst terrains. Carbon dioxide which is dissolved in groundwater to produce carbonic acid is also produced by plant root respiration and the bacterial decay of organic material. Locally sulphuric acid may occur due to bacterial metabolism, particularly in bogs. The weathering of pyrite and shales may also lead to the formation of sulphuric acid. The volume of limestone which may be dissolved varies in response to changes in a number of different chemical and physical parameters, a comprehensive explanation of which is beyond the scope of this report.

The land stability effects of karst processes are divided by Jennings (1985) into two separate categories, subsidence and collapse. Subsidence relates to mass movement processes affecting superficial deposits such as soils and weathering mantles. Collapse relates to geologically sudden mass movements of the bedrock.

4.4.2 Mass movement of superficial deposits

Because of the enhanced solubility of limestones a sharp break may occur between the bedrock and the overlying deposits. A lack of insoluble material in limestones may result in the development of a very thin soil layer. A thin layer of superficials may be less prone to mass movement. The relatively rapid movement of water into the underlying bedrock will also inhibit debris slides and other water-aided mass movements. Precipitation of calcite from carbonate-rich groundwaters may cement gravels within the overburden as can be seen in the banks of the River Derwent. The term calcrete is commonly applied to such cemented gravels.

4.4.3 MASS MOVEMENT OF BEDROCK

As noted above the term collapse is used in relation to mass movement of the bedrock. This may occur either at the surface or subsurface.

Surface collapse may result from undercutting of slopes by streams. This process may be more effective in limestone areas than in less soluble terrains.

Solution may disturb the stress conditions in a volume of rock. These stresses may reflect a permanent tectonic stress or a lithostatic loading due to the overlying rock and superficial deposits. Solution may lead to decompression and the opening up of joint planes resulting in rockfall or roof collapse.

Similarly the rapid draining of water from underground caves, or mine workings, may remove support from the cave walls giving rise to wall or roof collapse. The reverse may also occur where an influx of water perhaps after heavy rain may increase hydrostatic pressure leading to failure of roof or wall rocks. Volume changes associated with wetting and drying of shales may also play a role in collapse.

However the dominant process triggering collapse is percolation of water along fissures and solution of walls by cave streams.

The closed depressions formed in limestones are called dolines (the term includes swallow holes or sink holes). A sinkhole is a special case where a stream is seen to disappear within a doline. In America the term sinkhole covers all closed depressions, irrespective of whether there is a sinking stream or not. Culshaw and Waltham (1987) adopted this usage of the term in their description of solution cavities in carbonate rocks. Culshaw & Waltham (op. cit.) describe four main types of sinkhole.

A. Solution sinkholes

These result from a natural lowering of the rockhead surface. Their rate of formation is slow and they may not represent an engineering hazard. Their development may be controlled by geological factors such as faults or the outcrop edge of impermeable units.

B. Collapse sinkholes

These develop by surface collapse into caves. Although considered to be a rare occurrence, the possibility of such a collapse should be considered prior to any development.

C. Subsidence sinkholes

These form in the overlying superficial deposits due to unconsolidated material being flushed into fissures in the underlying limestone, This surface collapse may occur gradually as the superficial deposits are progressively washed through the fissures. However cohesive units within the drift may form a bridge halting upward migration of the subsidence. The void created beneath this bridge represents an engineering hazard as loading may result in instant failure.

D. Buried sinkholes

These represent infilled solution sinkholes in the rockhead surface. The main engineering hazard results from the differential compaction properties likely to be present at the edge of the sinkhole.

A common component of the this type of sinkhole is the existence of an underground system of fissures and/or caves through which water can migrate. The size and extent of these cavities determines the scale of the engineering problems which may be encountered. Unless caves can be entered and subsurface mapping carried out the subsurface extent of dissolution features can only be ascertained by drilling. Within the study area no large-scale caves or cavities were seen in either natural outcrop or within limestone quarries. Fissures examined had a maximum width of 1.5 m and a vertical extent of only a few metres.

4.5 Landslips

Landslips have been identified in a number of places in the district. Their position is indicated on Maps 5 and 9 (Figures 10 and 12).

Landslips on the north side of the River Derwent at [0543 3033] and in the Marron valley at Calva Hall [0605 2650] and near Gatra [0685 2095] are the result of slope failure on boulder clay.

Oversteepening and undercutting of the lower slopes by river erosion, which effectively stresses the slopes by removal of support, may lead to mass movements in the form of shallow translational and/or rotational landslips. Care should be taken not to undercut further the toe of the bank or load the top in slipped areas, or in other locations where similar geological conditions exist, as this may reactivate existing slips or trigger new ones, unless appropriate remedial measures are taken. Where construction activities are proposed, a site investigation and subsequent appropriate stability analysis should be carried out to assess the effect of the construction work on the stability of the slope.

Rather more extensive areas of landslipped ground have been mapped on the steep slopes west and north of Moorside Colliery [055 215] where thick beds of Coal Measures sandstone and underlying mudstones and siltstones, have slipped. Oversteepening of the hill slopes in this instance is not the result of recent river erosion. It is probable that this oversteepening developed during the last phases of deglaciation. The landslipping may therefore be an immediately post-glacial event. Such landslips may now be inactive or at least may perhaps be regarded a comparatively stable unless disturbed by groundworks.

4.6 Made and disturbed ground

This section should be read in conjunction with Map 6 and Figure 11. The nature of the categories of deposit shown on the map will be outlined together with the development problems associated with each deposit.

4.6.1 Worked out opencast coal seam area

Opencast coal mining is concentrated in the north-west corner of the district around the villages of Broughton Moor and Great Broughton. Extraction at a number of sites has been completed and the ground restored to its original use as farmland. The majority of workings are backfilled with overburden originally removed from them. However part of the Blooming Heather site was used as a landfill site. Those workings which were backfilled with overburden will contain a fill of relatively uniform composition. Tackling problems associated with worked-out opencast sites is aided by the fact that the position and depth of worked areas is documented on British Coal completion plans.

The main problems associated with worked out opencast coal seams are:

i) Differential compaction: although settlement of the backfill will occur within a few years of restoration, problems may still occur at the margins of worked-out areas where foundations may straddle areas of both fill and undisturbed ground.

ii) Leachates: the overburden used as backfill may contain shales and pyrite which could lead to the production of toxic leachates. A similar problem may arise where miscellaneous waste has been used as backfill. These leachates may be hazardous to health or may attack concrete foundations.

iii) Landfill gas: landfill gas is the collective name given to any gas generated by physical, chemical or microbial processes operating on waste material deposited in landfill sites. Methane and carbon dioxide produced by the degradation of organic matter are the main components of landfill gas mixtures (see Section 4.7). The principal problems associated with the migration of landfill gas are explosions, toxicity, fire and health risks.

iv) Engineering properties: where overburden has been used to backfill worked-out opencast areas the relatively homogeneous nature of the fill means that its geotechnical properties can be characterised. However the varied nature of domestic, industrial and agricultural waste used as backfill will result in a complex range of geotechnical properties within a site.

v) Voids: voids may occur in sites backfilled with miscellaneous waste. These provide obvious engineering difficulties and their position and extent can only be determined by comprehensive site investigation.

vi) Heave: this results from the swelling of mudstone fragments used as backfill and may cause foundation problems in any future development.

4.6.2 Miscellaneous Waste

This category includes domestic, agricultural, building, industrial and quarry waste. A list of Cumbria County Council waste disposal sites is shown on Map 6. This list is also shown in Table 7, together with details of the licence number, current status and type of waste material placed in the sites. The landfill sites are dominantly abandoned limestone and sandstone quarries, though as stated previously worked-out opencast workings have been used at Broughton Moor.

Problems of landfill gas production, differential compaction, variable engineering properties, leachates and voids will affect any future development of these areas. Details of these particular problems are outlined in the previous section.

4.6.3 Colliery waste

A number of areas of colliery spoil have been identified throughout the area. These consist of either flat spreads of spoil, as at Broughton Moor, or as spoil heaps, the most conspicuous of which is that associated with Buckhill Colliery [0586 3198].

The colliery waste consists of a mixture of rock fragments, mainly mudstone and sandstone, with carbonaceous and pyritous material also present. The principal problems associated with the colliery spoil are spontaneous combustion and production of toxic gases. Problems associated with heave and sulphuric leachates may also arise.

4.6.4 Landscaped and disturbed ground

This category includes the extensive spreads of man-made ground found in urban areas and the more localised tracts associated with road and railway lines. The nature of the disturbance, whether reworking of original superficial deposits or importing of new material, is highly variable and exact boundaries of such materials are difficult to define. Particular problems occur within landscaped opencast sites where the original drift cover may remain *in situ* and yet its engineering properties may have been affected by the opencast operation. Areas within opencast operations which have formerly been the sites of spoil mounds, baffles or plant may not possess the same engineering properties as undisturbed drift.

4.7 Gases

4.7.1 Introduction

Several gases occur naturally within the rocks and soils of any area. Many of these are released gradually into the environment, though this release may be hastened by such activities as mining and quarrying. Most common are methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S) and radon (Rn). In addition to these naturally-occurring gases others may be generated by human activity. Most notable among these is landfill gas (LFG) the main constituent of which is methane, produced by anaerobic degradation of organic matter in landfill sites. Carbon monoxide (CO) and other gases may be formed during mining operations. All of these gases are potentially hazardous. In the interests of public safety it is important that proper account should be taken of them in planning of land use, control of development, and under environmental protection measures, as well as in relation to existing development in affected areas. This requires detection and, where appropriate, precautionary and remedial action. Many aspects of this important topic are beyond the scope of this report. Presented here are brief notes on the main geological environments of these gases. These geological environments e.g. areas of coal mining, karst or made ground have been described in the previous sections and are shown on Maps 5 and 6 and Figures 10 and 11. These maps, together with the sections describing the different categories of hazard, should be read in conjunction with this section on gases. The increasingly large technical literature on potentially hazardous gases should be consulted for further details including management and remedial procedures.

4.7.2 METHANE (CH_4) is also known to coal miners as 'fire damp'. The following notes refer to natural methane. The presence of this gas as the major constituent of landfill gas is mentioned below.

Methane is generated by thermochemical reaction of the consolidated organic material in coal seams and organic-rich rocks. Only a small volume of the methane generated by coalification will be retained in a coal seam. Methane content varies both within and between coal seams. Contents of up to 20 m^3/ton have been recorded from British coal seams. In general methane content appears to increase with coal rank and vertical depth to the coal seam. The rate of emission of methane gas into mine workings will depend largely on the permeability of the coal seams. This will be increased by the presence of migration paths such as sandstone bodies or faults or other fractures. Disturbance by mining activity may also increase permeability.

Methane forms a highly explosive mixture when present in concentrations of between 5 and 15 per cent in air. It is a well known and widespread hazard in most underground coal mines in Britain. Elaborate ventilation procedures are adopted to remove methane from working mines in order, so far as possible, to prevent the build up to explosive concentrations.

Methane continues to be released into abandoned coal workings and without artificial ventilation high, and in places potentially explosive, concentrations may build up. Discharge of methane from old workings may occur through natural fissures or fissures resulting from collapse of workings, through porous rock units such as sandstone beds, or through abandoned shafts, adits or boreholes. British Coal publish technical advice on the treatment of abandoned mine workings in order to minimise the risks of methane accumulation (National Coal Board, 1982).

Methane may be present within a variety of rock types and may be released into the atmosphere. Where there is no impermeable cover to trap concentrations of the gas this discharge will normally take place gradually and over a wide area becoming very rapidly diluted with air and generally posing no particular risk. However care should be exercised in the construction of boreholes, sewers, water pipelines, tunnels, cellars, wells and other excavations in which methane and other gases may collect in potentially dangerous concentrations. The disastrous explosion which resulted from a build up of methane in such a situation at Abbeystead in Lancashire (HMSO, 1985) emphasises the potential danger.

4.7.3 CARBON DIOXIDE (CO_2) known to coal miners as 'choke damp', is both the normal product of complete combustion of organic substances and of respiration. It is present in ordinary air in very small amounts (approximately 0.03 per cent). In old workings the oxidation of timber, coal and other organic materials may remove a good deal of oxygen from the air leading to the production of deoxygenated air, the main constituents of which are carbon dioxide and nitrogen. This mixture was known to coal miners as 'black damp'. Dissolution of limestone by normally acidic rainwater produces carbon dioxide, concentrations of which may build up in cavities, either natural or man-made, in limestones or nearby deposits.

Neither carbon dioxide nor 'black damp' are toxic but neither will they support combustion or respiration. As carbon dioxide is appreciably heavier than air it will concentrate readily in the base of excavations or voids. The possible presence of these gases should be considered and due care exercised in old workings, excavations or tunnels in deposits likely to contain or generate concentrations of these gases.

4.7.4 HYDROGEN SULPHIDE (H_2S) or 'stink damp' may be produced in a number of ways including bacterial action on sulphide-bearing rocks or by the reaction between acid ground, or mine water, and sulphides, the most common of which is pyrite. Concentrations of the gas may be encountered in old workings. Hydrogen sulphide is extremely toxic.

4.7.5 RADON (Rn) is a natural radioactive gas produced by the decay of radium, which in turn is the product of the radioactive decay of uranium. Radioactive minerals which contribute to radon production are present in virtually all rocks and soils though usually in exceedingly small amounts. However because there is a great variation in the uranium content of different rocks the levels of radon generation show great regional variation. In general the highest radon levels occur in regions underlain by rocks such as granite, which commonly contain comparatively large amounts of radioactive minerals. Other rock types are today known to be significant sources of radon. Notable amongst these are mudstones which contain appreciable amounts of organic matter with associated concentrations of radioactive elements. Not only do some rocks generate comparatively high levels of radon but certain rocks and geological structures may act as traps and conduits for the gas.

Radon normally passes gradually from the rocks and soil into the atmosphere where it is usually diluted to very low levels. However in certain circumstances concentrations may build up and can form a potential hazard.

In recent years a considerable amount of research has been conducted on radon production and the associated potential risks to health. To date much of this work has focused on areas already known to have a high radon potential. Very little information is available for the present district though the following comments summarise what is known.

Within the Great Broughton-Lamplugh area the rocks most likely to generate significant levels of radon are mudstones, particularly those with a high organic content, and perhaps some limestones. Dark mudstones forming the marine bands of the Coal Measures and perhaps parts of the Hensingham Group are the most probable sources. Mudstone sequences of similar age elsewhere in Britain, e.g. the Edale Shales of Derbyshire, are known to be significant producers of radon. However it is likely that the Hensingham Group contains fewer marine shales with enhanced uranium levels and is therefore likely to generate less radon. Radon may also be generated in parts of the Dinantian limestones although these rocks may have a more important role as high permeability reservoirs for, or conductors of, the gas.

Limited measurements of radon levels have been made in west Cumbria, although not specifically within the present district. There is insufficient data from soil gas to make any predictions of likely levels within the district. However, it is known that some houses underlain by limestones are above the Action Level of 200 Becquiels per m^3 (data from NRPB and Institute of Environmental Health Officers surveys). In the hematite mines of the Egremont area, measurements made shortly before the mines' closure in the 1970s showed up to 400 Bq/litre in air. No figures have been found for radon levels in air in coal mines in west Cumbria. Large faults, of which many occur within the district, may also act as important conduits for radon.

For the most detailed information advice should be sought from either the National Radiological Protection Board, or the Department of Environment.

4.7.6 CARBON MONOXIDE (CO) and other toxic gases such as various oxides of nitrogen may be produced as a result of incomplete combustion in mine fires. Pockets of these gases may be encountered in old workings.

4.7.7 LANDFILL GAS is the collective name given to a mixture of gases produced as end products of the physical, chemical and microbial degradation of the organic components of landfill sites. Methane and carbon dioxide are the main constituentsalthough, depending on the nature of the landfill material, other gases may be present in smaller proportions.

Recent years have seen an increasing realisation and appreciation of the problems posed by the generations of large volumes of this gas within landfill sites. Particular attention is now directed towards understanding possible migration routes for this gas from its site of origin and to minimising risks of infiltration of the gas into buildings. Useful information on the control and management of landfill gas is contained in the following papers: Department of the Environment, 1986; Her Majesty's Inspectorate of Pollution, 1989; Young and Parker, 1983; Campbell and Young, 1985 and the report on the non-statutory Public Inquiry into the gas explosion at Loscoe, Derbyshire.

4.8 Seismicity

Minor seismic events are more frequent in Britain than is commonly supposed. Whereas many of these can be traced to such causes as the collapse of underground workings or large-scale quarry blasting, a comparatively large number appear to be small natural earthquakes.

No records have been found of earthquakes originating within the district. However Young & Armstrong (1989, p.38) record two very minor earthquakes with epicentres in the adjoining Maryport area. These events may have been related to collapse of old mine workings though movement on the Maryport Fault or related fractures is also possible.

Davidson 1924, Musson et al., 1984A & B and Musson 1987 have reviewed historical records of seismic events in a wide area of south-west Scotland and north-west England, including the present district. The effects of several of these have been felt within the district or the immediately adjoining areas. Reliable historical records of such events within the district have been documented by Musson et al., 1984B and Musson, 1987.

The Carlisle earthquake of 9th July 1901 was felt over a wide area of Cumbria. At Lamplugh several people felt the shock which at the time was ascribed to thunder. On 2nd October 1915 an earthquake, also centred in the Carlisle area, was felt over a wide area of southern Scotland and north-west England. In the present district a stone wall collapsed at Little Clifton, a picture fell from a wall at Brigham and in Great Broughton a man was thrown against a wall, cutting his head. Other reports from Great Broughton refer to the rattling of houses and furniture for up to seven seconds, accompanied by a loud rumbling noise.

The Carlisle earthquake of 1979 was felt across a wide area of Cumbria although the effects generally appear to have been slight with sounds resembling thunder and some rattling of household objects. Slates were loosened on a roof at Row Brow, Dearham and some alarm was caused to staff at the nearby Cockermouth Cottage Hospital. The microseismic epicentre of this event was placed at Longtown.

The maximum intensities of these events in west Cumbria is estimated at about 5 MSK. The position of the epicentre suggests movement of a structure deep beneath the Solway basin.

More recent events, including the North Wales earthquake of 19th July 1984 and the Bishop's Castle earthquake of 2nd April 1990, were felt over a very wide area of Britain, presumably including west Cumbria, although there are no published references to specific effects in the present district.

Whereas there are no grounds for regarding this district as especially prone to seismic activity, the records of these events does highlight that here, as elsewhere in Britain, the possibility of seismic events of unusual intensity does exist. This should be taken into account when designing specific types of sensitive structures (Ove Arup and Partners, *in press*).

4.9 Sterilisation of mineral resources

Past, present and potential future mineral resources of the district have been discussed in Section 3. Areas of potential mineral resources are delineated on Map 8 and Figure 9. It is important to take all of these factors into account in planning and development in order to avoid possible sterilisation of potentially workable minerals.

CONCLUSIONS

The study has produced a comprehensive re-interpretation of the geology of the district. The new 1:10 000 geological maps, 1:25 000 thematic maps, reports and databases provide a thorough framework for the evaluation of geological issues in land-use planning and planning decisions. The principal geological factors highlighted by this work are:

1. Areas of shallow coal mining exist which may present stability problems. Many shafts and adits have been identified within the area, although undoubtedly others exist.

2. Large, underground voids related to iron ore working exist. The behaviour of these voids is difficult to predict.

3. Made ground and fill is extensive. The variable nature of these deposits makes prediction of related problems difficult. Backfilled opencast workings, quarries and former colliery sites have been identified. However, smaller quarries and pits undoubtedly exist and may cause localised instability.

4. Gas production, either within old coal workings, natural limestone cavities or from waste within backfill sites may prove hazardous.

5. Dissolution of limestone may result in surface instability. This phenomenon occurs on the limestone outcrop and where the limestone is overlain by mudstones, siltstones and sandstones of the Hensingham Group.

6. Slopes may prove unstable where these are steepened or undercut by natural erosion or by excavation, or are overpressured when materials are deposited or structures built on them.

7. Resources of coal, limestone, and sand and gravel exist within the district. These should be taken into account in forward planning of land use. Resources of other minerals such as sandstone also occur but are unlikely to be of economic significance.

This study has attempted to collate and evaluate all relevant geological data. However the maps and reports produced should not be seen as an alternative to a detailed site investigation when planning a development project. The reader is strongly advised always to consult primary sources of data. Where mining is suspected the mine plans and shaft atlases maintained by British Coal and the abandonment plans of non-coal mines held by the Health and Safety Executive should be consulted.

REFERENCES

ANON. 1920A. Refractory materials: fireclays. *Special Reports on the mineral resources of Great Britain; Memoir of the Geological Survey of Great Britain*, Vol. 14.

— 1920B. Refractory materials: ganister and silica-rock-sand for open-hearth steel furnaces-dolomite. *Special reports on the mineral resources of Great Britain. Memoir of the Geological Survey of Great Britain*, Vol. 6.

ARKELL, W J, and TOMKEIEFF, S I. 1953 (reprinted 1973). *English rock terms chiefly as used by minerals and quarrymen*. (London: Oxford University Press.)

BRAITHWAITE, P A, and SEAGO, K L. 1988. Regional study of the West Midlands area to locate old limestone mine workings. pp.279–286 *In Geological Society Engineering Geology Special Publication,* No. 5. BELL, G G, CULSHAW, M G, CRIPPS, J C, and LOVELL, M A (editors).

CAMPBELL, D J V, and YOUNG, P J. *Landfill Monitoring — Landfill Gas*. Paper presented at Landfill Monitoring Symposium, Harwell, 23 May 1985. (Copies of proceedings available from Environmental Safety Centre, Building 7.12, Harwell, Didcot, Oxfordshire OX11 0RA).

CANTRILL, T C *In* Strahan, A, GIBSON, W, SHERLOCK, R.L. and DEWEY, H. 1920. Pre-Carboniferous and Carboniferous bedded iron-ores of England and Wales. *Special Reports on the Mineral Resources of Great Britain*; *Memoir of the Geological Survey of Great Britain.*

CULSHAW, M G, and WALTHAM, A C. 1987. Natural and artificial cavities as ground engineering hazards. *Quarterly Journal of Engineering Geology*, Vol. 20, 139–150.

CUMBRIA COUNTY COUNCIL. 1989. *Cumbria Coal Local Plan*. County Planning Departmentt, Cumbria County Council, Kendal.

DAVIDSON, C. 1924. *A history of British Earthquakes*. (Cambridge University Press.)

DEPARTMENT OF THE ENVIRONMENT. 1991. *Landfill gas: a technical memorandum providing guidance on the monitoring and control of landfill gas*. (London: HMSO.)

DUNHAM, R T. 1962. Classification of carbonate rocks according to depositional texture. pp.108–121 *In* Classification of carbonate rocks. HAM, W E (editor). *Memoir of the American Association of Petroleum Geologists,* Vol. 1.

FORSTER, A. 1988. The geology of the Castlefields Mine, Dudley and its effect on the stability of the mine roof. pp.287–292 *In Geological Society Engineering Geology Special Publication,* No. 5. BELL, G G, CULSHAW, M G, CRIPPS, J C, and LOVELL, M A (editors).

FREEMAN FOX LTD. 1988. *Treatment of disused mine openings*. (London: HMSO.)

GALLOWAY, R L. 1898. *Annals of coal mining and the coal trade,* Vol. I. (London: Colliery Guardian), reprinted 1971 (Newton Abbot: David & Charles).

— 1904. *Annals of coal mining and the coal trade,* Vol. II. 409pp. (London: Colliery Guardian), reprinted 1971 (Newton Abbot: David & Charles).

GARRARD, G F G, and T , R K. 1988. Collapse mechanisms of shallow coal-mine workings from measurements. pp.181–192 *In Geological Society Engineering Geology Special Publication,* No. 5. BELL, G G, CULSHAW, M G, CRIPPS, J C, and LOVELL, M A (editors).

GREENWELL, G C. 1888 (3rd edition). *A glossary of terms used in the coal trade of Northumberland and Durham*. (London & Derby: Bemrose & Sons), reprinted 1970 (Newcastle upon Tyne: Frank Graham).

HER MAJESTY'S INSPECTORATE OF POLLUTION. 1989. The Control of Landfill Gas. *Waste Management Paper,* No. 27. (London: HMSO.).

HER MAJESTY'S FACTORY INSPECTORATE. 1985. *The Abbeystead Explosion: A report on the investigation by the Health and Safety Executive into the explosion on 23 May 1984 at the valve house of the Lune / Wyre Transfer Scheme at Abbeystead.* (London: HMSO.)

JENNINGS, J N. 1985. *Karst Geomorphology*. (Oxford: Blackwell.)

JONES, J H. 1957. Report on the Cumberland Coalfield. *In Cumberland, with special reference to west Cumberland Development Area: A survey of industrial facilities*. DAYSH, G H J, and WATSON, E M. (Cumberland Development Council Ltd and West Cumberland Industrial Development Co Ltd.)

LONGWORTH, T A. 1988. Monitoring of ground movement above an abandoned limestone mine. pp.299–306 *In Geological Society Engineering Geology Special Publication*, No. 5. BELL, G G, CULSHAW, M G, CRIPPS, J C, and LOVELL, M A (editors).

MUSSON, R M W, NEILSON, G, and BURTON, P W. 1984A. Microseismic reports on historical British earthquakes. 1: Northwest England and southwest Scotland. *Global Seismology Unit Report,* No. 207(a). (Keyworth, Nottingham: British Geological Survey.)

— — — 1984B. Microseismic reports on historical British earthquakes 1: Northwest England and Southwest Scotland. *Global Seismology Unit Report,* No. 207(b). (Keyworth, Nottingham: British Geological Survey.)

— 1987. Seismicity of Southwest Scotland and Northwest England; with a catalogue of earthquakes within 75 km of Chapelcross. *Global Seismology Unit Report,* No. 316. (Keyworth, Nottingham: British Geological Survey.)

NATIONAL COAL BOARD. 1982. *The treatment of disused mine shafts and adits*. (NCB Mining Department.)

OVE ARUP and PARTNERS. In press. *Preliminary study of UK seismic hazard and risk: summary report*. (London: HMSO.)

PIGOTT, R J, and EYNON, P. 1978. Ground movements arising from the presence of shallow abandoned mine workings. pp.749–780 *In Proceedings of the First Conference on Large Ground Movements and Structures, Cardiff, 1977*. GEDDES, J D (editor). (London: Pentech Press.)

REPORT OF THE NON-STATUTORY PUBLIC INQUIRY INTO THE GAS EXPLOSION AT LOSCOE, DERBYSHIRE, 24 MARCH. 1986. (Report available from P E Baldy, County Information

Officer, Derbyshire County Council, County Offices, Matlock, Derbyshire DE4 3AG).

RICHARDS, J A, and MILLER, A. 1988. Roof-fall observations at Castlefields Mine, Dudley. pp.293–298 *In Geological Society Engineering Geology Special Publication*, No. 5. BELL, G G, CULSHAW, M G, CRIPPS, J C, and LOVELL, M A (editors).

TAYLOR, B J. 1978. Westphalian. pp.180–188 *In* The geology of the Lake District. MOSELEY, F (editor). *Yorkshire Geological Society Occasional Publication,* No. 3.

WOOD, O. 1988. *West Cumberland Coal 1600–1982/3.* (Cumberland and Westmorland Antiquarian and Archaeological Society. Extra Series 24.)

YOUNG, P J, and PARKER, A. 1983. The Identification and Possible Environmental Impact of Trace Gases and Vapours in Landfill Gas. *Waste Management and Research,* Vol. 1, 213–226.

APPENDIX A

Data sources

Field Survey

This is undertaken at the 1:10 000 scale by a geologist on foot. It involves the examination, recording and interpretation of surface morphology and natural and man-made exposures. It attempts to delimit solid and drift deposits and checks for evidence of the existence of old shafts, adits, underground workings and abandoned and active pits and quarries. The amount of detail identifiable is heavily dependent on the degree of exposure and the nature of the landforms. In a heavily drift, covered area like the current district there is often little evidence of the solid rocks.

Deep-mined coal boreholes and shaft records

These provide a log of strata penetrated by a borehole or shaft. They may start at ground level or from an underground position. The method of drilling the boreholes may be either open-hole or cored. Drilling was in progress during the investigation, mostly for opencast coal exploration, although the results are confidential. Boreholes and shafts are lodged in the BGS archive as text but are conventionally converted to graphic form at a standard scale (1:480). The records are of variable quality and the absence or inadequacy of certain details, for example surface level, location and strata record, is common. They are however the main source of information about lithological variation across the district.

Deep-mined coal abandonment plans and opencast completion plans

These are a record of underground working in individual coal seams and, ideally, will show the extent, date and depth of the working, coal thicknesses, faulting, presence of water and the location of shafts and drifts transecting the seam. Initially their scale varied. The opencast completion plans indicate the tonnage extracted from each seam and dates of working and restoration. These documents represent the results of a 'measured survey' and are therefore a good datum if seam correlation is known, although inevitably some of the early plans are lacking in vital detail. Completion plans from private sites tend to be much less comprehensive.

Site investigation boreholes, trial pits and reports

In the past, boreholes were only rarely put down to investigate ground conditions prior to construction; the exceptions were structures such as bridge foundations or harbour works. Today almost every development, from minor residential to major civil, is preceded by some form of site survey, that is, trial pit, or boreholes or probe. However in an essentially rural area such as the present district such site investigations are comparatively few. BGS holds the records for 251 boreholes and trial pits made for this purpose in the district.

Iron ore and other mineral exploration boreholes

In the limestone outcrop, particularly of the southern part of the district, numerous boreholes were drilled last century in search of hematite iron ore. These holes were generally cored, at least in part. The cores have almost all been long since lost although some representative specimens, especially those of palaeontological interest, are in the BGS collections. The logs are held by BGS on an open file basis.

A small number of boreholes have been drilled to prove limestone reserves, mainly adjacent to working quarries. The records of these holes are confidential.

Existing geological maps

There have been two previous full geological survey of the district. The first was undertaken in the 1880s and early 1890s, the second between 1921 and 1927. In addition a partial revision of the first survey was undertaken in 1894. These surveys produced field slips and published six-inch geological maps on the Cumberland County Series grid. Whereas these older surveys did not have the benefit of the more recent site investigation and opencast coal exploration data the work was carried out when several of the area's collieries and quarries were still working. The previous surveyors therefore had access to exposures which are no longer extant. In compiling a modern survey these historical data provide an essential foundation on which to base modern interpretations.

Local authority data

Cumbria County Council Waste Disposal section provided information on the location of known landfill sites and the composition of deposited waste. The County Engineer's Department made available large numbers of borehole records, especially those relating to major road improvement schemes. These have been incorporated into the BGS archive of site investigation boreholes, trial pits and reports.

Geological reports and journals

The bibliography contains a selection of those documents consulted during the study; they range from memoirs describing the geology of the region to academic papers concerning specific subjects.

APPENDIX B

The Borehole Database

BGS holds an extensive collection of paper records which describe the strata encountered during the sinking of boreholes, mineshafts and trial pits, and in sections measured by BGS geologists. These records represent a major source of factual data, in some parts the only source, for geological investigations and interpretations within the study area. The paper borehole record is considered to be the authoritative primary record and there has been no attempt to replicate it on the computer. A computerised database for the project area was seen as a way of utilising the data held in the paper archive to maximum effect by allowing rapid and flexible retrieval of a wide range of information.

All borehole and shaft records in the project area have been coded following a format which has been developed within BGS. This work has resulted in the establishment of a simple system whereby borehole information can be assigned to two tables of data, on the basis of the following criteria:

a) All data which describes a feature of the borehole itself, for example, its name, its location by National grid reference, the date it was drilled, height above (or below) sea level.

b) All information relating to samples taken from point depths below the surface for that borehole.

A complete list of fields in each of these tables within the borehole database is given below.

The data is currently held in an ORACLE relational database management system running on a mainframe computer at BGS Edinburgh. It can be interrogated by menu or specifically by using a query language (SQL). It may be used as an index to available records or for detailed geological analysis. Retrieved data may be manipulated and displayed using a number of statistical and graphic application packages and it is possible to automatically produce graphic vertical sections, scatter-plots, contour maps and three-dimensional diagrams.

List of fields in the BGS Newcastle borehole database:

a) **Index table**

OS 1:10 000 sheet number*	Reliability
Accession number and suffix*	Start point
National grid reference and accuracy	Inclination
	Drilling date
Borehole name	Geologist
Comments	Drilling method
Other borehole number	Borehole diameter
Surface level and accuracy	Consulting engineer
Confidentiality	Drilling contractor
Purpose	Water strike
Originator	

b) **Lithological table**

OS 1:10 000 sheet number*	Stratigraphy
Accession number and suffix*	Reliability
Depth	Workings
Lithology	Comments
Base of bed	

* the primary key index

APPENDIX C

Glossary of Geological and Mining terms used in west Cumbria

Like any other trade, mining and quarrying have over the centuries evolved a wide vocabulary of specialist terms. Some of these are common to these industries wherever they have been practised and several have passed into widespread use in the English language where they are widely understood outside of the mining and quarrying fraternity. A number of words have been adopted by the geological sciences, although in some instances with major change from their original meaning, e.g. sill and dyke. Many words have however remained unique to the trades which coined them. Although numerous, such words are found in several mining areas and their meanings commonly differ, in some cases markedly, from area to area. Like all such mining communities west Cumbria has developed a distinctive local vocabulary. Early mining literature and old documents such as mine plans, reports and borehole records abound with these words. Any reference to such original data sources will bring the student into contact with these terms.

To aid understanding the following brief glossary has been compiled. The meanings given relate specifically to west Cumbria though in some instances use of the term in other parts of the country is given. As in most trades mining engineers moved from one part of the country to another taking their local jargon with them. The work of such visiting or immigrant specialists may be suspected if the usual Cumbrian meaning proves difficult to interpret or appears ambiguous.

The following is a guide to the terms most commonly encountered in west Cumbrian records; it is not claimed to be in any sense exhaustive. It has been compiled from a wide variety of sources. For more detailed information on the often obsolete terms the following sources are recommended: - Arkell & Tomkeieff, 1953; Galloway, 1898; 1904; Greenwell, 1888.

ASHLAR	Squared blocks of building stone or the masonry built of this.
BALL	Clay ironstone nodule.
BAND	i) Bed. ii) Layer of shale.
BANK	Surface level of mine shaft.
BANNOCK	One of the major seams of the coalfield. Eastwood et al. (1931, p.121) suggest that the name is derived from the fact that it is normally a split seam of two or occasionally more leaves. The partings are normally fireclay or shale. Arkell & Tomkeieff (1953, p.3) note the use in Yorkshire and north Staffordshire of bannock or 'bannocking dirt' for any argillaceous rock forming the roof of a coal seam. They further note that in Yorkshire a seam of dirt running in between coal is sometimes 'bannocked' or taken out before the coal.
BASSET	Outcrop.
BASTARD	Impure or inferior e.g. BASTARD FIRECLAY.
BAT (BATT)	Carbonaceous shale or shale interbedded with coal.
BELL PIT	An early form of shallow shaft from the bottom of which coal was worked in all directions until stability and ventilation prevented further progress. The form of the completed excavation is that of a bell.
BLACK METAL	An important seam in the coalfield, so named from the characteristic occurrence of dark grey or black shale as the roof bed.
BLACK STRIPE	Dark coaly shale.
BLAE (BLEAS)	Shale. Originally a Scottish term commonly used in Cumbria.
BOARD	Secondary cleavage or jointing in coal perpendicular to the main cleavage or jointing known as CLEAT. Also used for a working place or roadway in a mine driven at right angles to the cleat. Arkell & Tomkeieff (1931, p.9) note the use of the term 'BOARDS' in the Bristol and Somerset coalfield for laminated shale above a coal seam. They further record the use of the term 'BOARD COAL' for coal shaped or grained like boards.
BRASS	Pyrite.
BRASSY	An important seam in the coalfield so named from the common occurrence of pyrite within it and/or the adjacent beds.
BRAT COAL	Thin seams of impure coal, usually with carbonate and pyrite, commonly found at the roof of a seam.
BROCKRAM	Originally a Cumbrian miner's term for breccia. Subsequently used for breccia units with the Permian of Cumbria.
CAKING COAL	Coal which on heating intumesces and fuses together.
CALM (CAUM, COAM)	Sandy mudstone.
CANK, CANKY	Ferruginous altered rock.
CANNEL	Massive bituminous coal which exhibits a smooth or sub-conchoidal fracture and which does not soil the fingers. The ash content is generally so high that the residue after burning is equal in volume to that of the

	original sample. The name is said to be a corruption of 'candle' because it burns with a bright flame. Cannel is commonly present as a layer at or near the bottom of some seams, e.g. the Main Band. It is also found as a layer on top of some seams.
CASH	Soft shale parting.
CATHEADS (CATS-HEADS)	Clay ironstone nodules.
CATSCOPE	Ironstone nodules.
CAUM	see CALM
CAUMSTONE	Argillaceous limestone.
CLEAT	Joints or cleavage planes in coal more or less normal to the bedding. The term is often applied by miners to the better developed of two joint systems.
COAL-BALL	Calcareous concretion of mineralised plant debris found in coal seams.
COAL-PRINTS	Thin patches or films of coaly matter on bedding planes.
COAM	see CALM
CROW	Term used to denote a poor or impure bed e.g. CROW COAL.
DAY-DRIFT (DAY-HOLE, DAY-LEVEL)	Adit or level worked from surface.
DIRT	i) Seat-earth or fossil soil beneath coal seam. ii) Parting of mudstone or other material in coal seam.
DOUK (DOWK)	Tough compact clay.
DRIFT	Horizontal tunnel.
DYKE	In the Cumbrian coalfield a fault, usually of moderate to large throw. Igneous dykes are unknown in this coalfield.
EYE	The inset or landing station in a shaft.
EYE COAL	Coal showing numerous circular patches surrounded by cone-shaped fracture.
FAIKES (FAKES, FEKES)	Interlaminations of shale and sandstone. Also known as GREY BEDS. Originally a Scottish term for fissile sandy shale or shaly sandstone.
FAKES	see FAIKES
FAKEY-BLAES	Sandy shale or siltstone. Originally a Scottish term, occasionally used in Cumbria.
FAKEY SANDSTONE	Flaggy sandstone. Originally a Scottish term, occasionally used in Cumbria.
FAMP	Ochreous, decomposed limestone.
FEKES	see FAIKES
FIRECLAY	Clay or mudstone capable of making refractory or fire-bricks. Also a seam in the coalfield, so called from the common occurrence of an underlying thick fireclay seatearth.
FIRESTONE	Fine-grained siliceous sandstone resistant to fire and which can be used for hearthstones, grates and limekiln linings. The term is likely to have been used locally for any fine-grained siliceous sandstone irrespective of refractory properties.
FLAG (FLAGSTONE)	Sandstone which splits readily along bedding into slabs.
FLAKES (FLAIKES)	Shaly or fissile sandstone. Originally a Scottish term, occasionally used in Cumbria.
FLAIKES	see FLAKES.
FLAT (FLOT)	More-or-less horizontal orebody replacing limestone beds.
FLAT SHEETS	Cast iron plates used as a solid floor at the top or bottom of a shaft on which coal tubs were manoeuvred.
FLOOR	Base of a coal seam or base of a mine or quarry working.
FLOT	see FLAT.
FLUES	Shale.
FREESTONE	A sandstone, generally fine-grained, which can be sawn or otherwise dressed easily in any direction.
GANISTER	Fine-grained siliceous sandstones.
GINNEL	i) Irregular GUTS lining the irregular hematite orebodies. ii) An opening or crack.
GIRDLES, GIRDLE BEDS	Flattened nodules of hard stone, e.g. clay ironstone or sandstone, in softer beds.
GOAF	The space from which coal pillars have been extracted; an area of total extraction.
GOSSEN (GOSSAN)	Weathered ore.
GOUGE	Clay or broken rocks, mainly shale-filling fault fissure.
GREY BEDS	see FAIKES.
GULLETS	Vertical cracks, more-or-less open.
GUTS	Narrow to broad, more or less vertical bands of hematite ore of fairly regular shape and commonly in parallel groups following the major joints of the limestone.
GUTTY FLAT	A sheet-like body of hematite ore.
HAZEL (HAZLE)	Fine-grained sandstone.
HAZLE	see HAZEL.
HITCH	Small fault.
HUNGER	i) Dirty, mottled clay formed by the weathering of shale. ii) Crystalline calcium carbonate found in the joints of coal seams.
KIDNEY ORE	Mammillated hematite.
LINSTEY	Banded siltstone or interbeds.
LOUGH,	Cavity or vug in orebody or vein.

(LOUGH-HOLE)	
MEASURES	The rock sequence, (usually refers to Coal Measures).
METAL	Shale.
METAL STONE	Sandy shale. In Northumberland the term denotes shaly sandstone whereas in Staffordshire it has been used for ironstone.
MUCK	Apart from its use to denote a variety unspecified earthy materials the term has been used in the iron ore mines to describe a blackish mottled clay associated with hematite ore and perhaps in part derived from the weathering of iron ore.
MUSSELS	Fossil bivalves.
NIP	i) Washout. ii) Fault.
PARROT COAL	Cannel coal or gas coal, the name said to derive from the chattering noise on burning.
PARTING	A thin bed, generally of shale or clay.
PEN (-FIRESTONE; -GANISTER; -SANDSTONE)	A sandstone rock with carbonaceous rootlet traces.
PENCIL ORE	Conical fragments of fibrous hematite
PICK ORE	Hematite ore which could be worked with a pick without the need for blasting.
PINNEL	Boulder clay in Cumbria and elsewhere in northern England. Arkell & Tomkeieff (1953, p.85) note the 18th century use elsewhere of the term to denote coarse gravel or sandstone conglomerate.
PIPE CLAY	Clay suitable for making tobacco pipes.
PLATE	Shale.
POST	Thick bed of sandstone or limestone.
QUARTER	Usually denotes a quarter of a yard (0.22 m) e.g. Ten Quarters Seam. Three Quarters Seam from the common thickness of the seam where worked.
RATTLER	i) A Cumbrian term for a valuable variety of gas coal which is typically hard, compact, brittle, fine grained, sonorous when struck and resembles jet in appearance though less bright. The name is said to be derived from its common property of 'spitting' in a fire. The terms seems to have been used locally in Cumbria as more or less synonymous with cannel. ii) The name of one of the major seams of the coalfield, no doubt due to the composition of that seam. iii) A term used elsewhere to denote sandy shale, noted by Arkell & Tomkeieff (1953, p.94), although the term is not known to have been used in this sense in Cumbria.
RIDER	i) A thin seam of coal overlying a thick seam. ii) A mass of country rock within an orebody or vein. iii) A crust zone or fault.
RISE	i) The rocks or the area on the upthrow side of a fault. ii) A vertical shaft driven upwards from workings, usually in a metalliferous mine.
ROCK	Sandstone. Several prominent sandstones in the coalfield take their name from the coal seam they overlie, hence the Main Band Rock, the Six Quarters Rock etc.
ROOF	The bed above a coal seam.
SAGGAR (SEGGAR)	Coarse fireclay, so named from its use in making saggars or seggars — the protective clay containers in which ceramic wares are fired in pottery kilns.
SEAT (-CLAY; -EARTH)	The bed, usually clay, beneath a coal seam.
SEGGAR	see SAGGER.
SILL	i) Fireclay. ii) A persistent bed, usually of hard rock. Igneous sills are unknown in the Cumbrian coalfield.
SKAMY	Heterogeneous or impure e.g. skamy post, skamy shale.
SLATY	An important seam in the coalfield, the name presumably derived from the commonly rather fissile nature of the coal.
SMIT	A soft, red, greasy-looking form of hematite. It may be a disintegrated form of 'kidney ore'.
SMITH ORE	Soft earthy hematite.
SPAR	Calcite or dolomite
SPAR COAL	A variety of coal which breaks into long elastic 'spars' or rods.
SPLINT	Impure bituminous coal with a dull lustre and uneven fracture, intermediate between cannel and bituminous coal.
STONE RATTLER	Any hard rock.
STONE-DRIFT	A mine level driven in rock not coal or ore.
STONE	See METAL-STONE.
STONE SILL	Impure sandy fireclay.
SULPHUR	i) An old miners term for either fire damp (methane) or perhaps hydrogen sulphide. ii) Pyrite. iii) In some descriptions 'sulphur' may refer to crusts of yellow earthy jarosite group minerals on partially

	oxidised mudstones and coals.
THILL	The floor of a coal seam.
TOM	Black shale parting in coal seam.
TROUBLE	Fault.
VUG	An open cavity in a vein or orebody, commonly lined with crystallised minerals.
WHIN	Hard rock. In other districts the intrusive rock of a sill or dyke.
WHIRLSTONE	Sandstone (other than FREESTONE), sometimes applied to dolomite, limestone, siliceous limestone or shale.
WOOL	Sandy shale.
YARD	An important seam in the coalfield, the name derived from its characteristic thickness in many places.


Natural
Environment
Research
Council