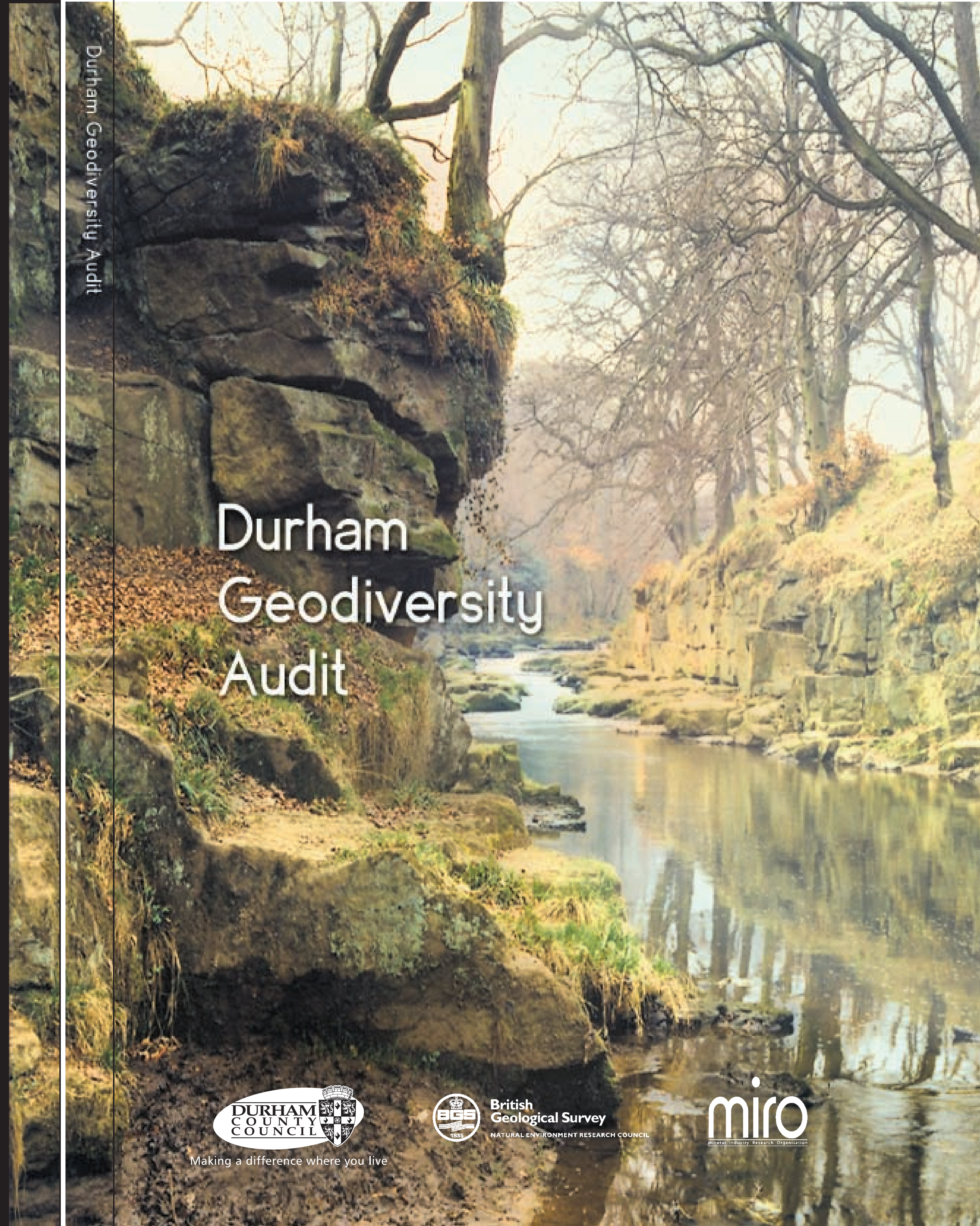
This Geodiversity Audit has been prepared by the British Geological Survey, in collaboration with Durham County Council, with funding from the Aggregates Levy Sustainability Fund (ALSF) administered by the Minerals Industry Research Organisation (MIRO) via the Office of the Deputy Prime Minister.

The Geodiversity Audit presents the results of a detailed evaluation of the geological and geomorphological features of the county. In so doing the wide spectrum of geological features are considered both as key factors in appreciating and explaining the county's earth science, and also as essential elements vital to the true understanding of the full range of natural and man-made features which characterise County Durham. Like its predecessor, the County Durham Geological Conservation Strategy, the present document is one of the first Geodiversity Audits to be undertaken on behalf of a County Council.

Durham Geodiversity Audit



Durham Geodiversity Audit

DURHAM COUNTY COUNCIL

Making a difference where you live

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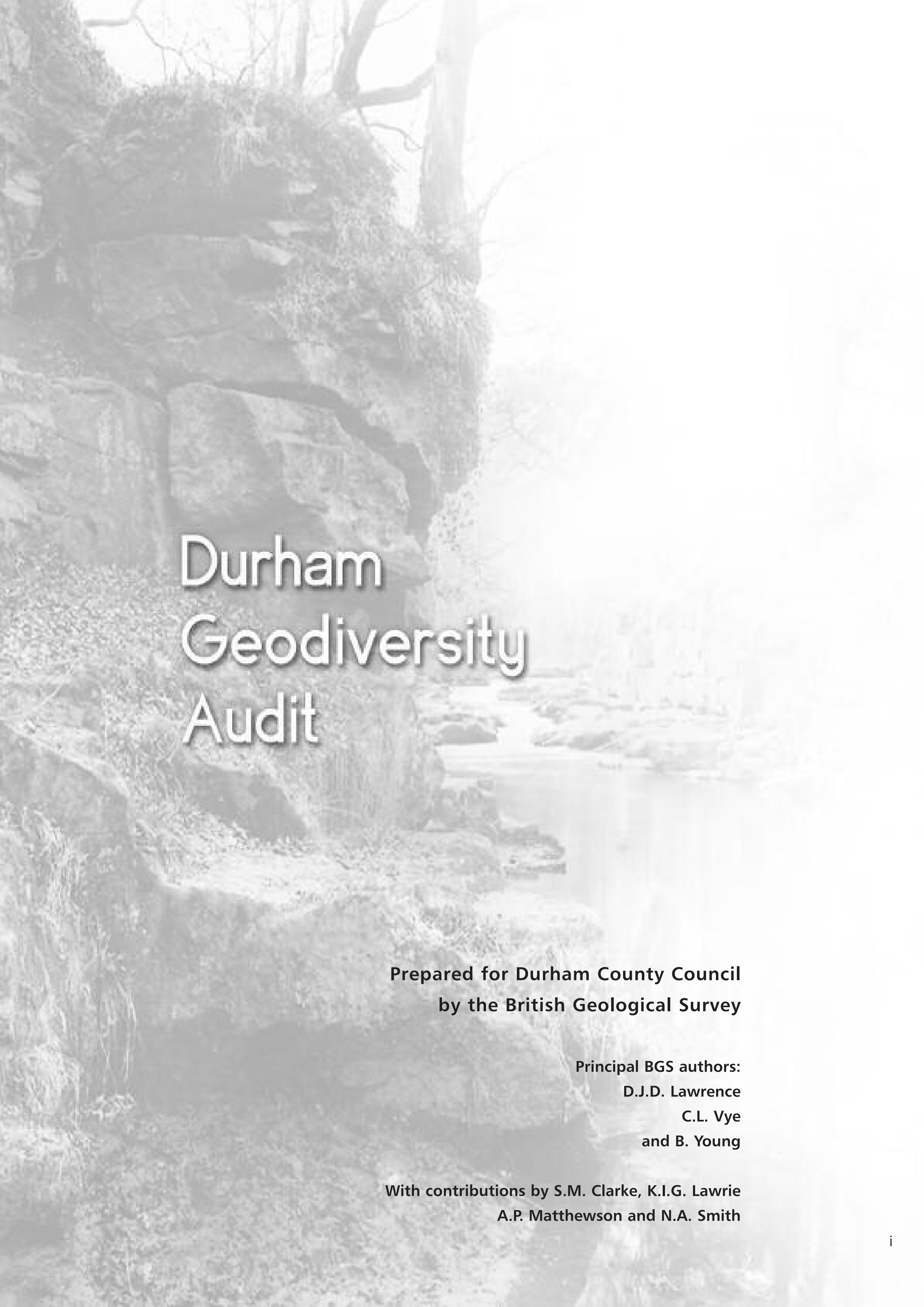

Durham Geodiversity Audit

Prepared for Durham County Council
by the British Geological Survey

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The British Geological Survey

This document has been compiled by the British Geological Survey (BGS). BGS is Britain's national geological survey and has been in existence since 1835. It assists both public and private sectors by advancing geoscientific knowledge of the UK landmass and its continental shelf, by systematic surveying, long-term monitoring, effective data management and high quality applied research. It provides comprehensive, objective, impartial and up-to-date geoscientific information, advice and services in the UK and overseas, and disseminates information in the community to promote the public understanding of science. The BGS is the largest of the research bodies administered by the Natural Environment Research Council (NERC), which was established by Royal Charter in 1965 to undertake and support basic and strategic research in the environmental sciences and which is independently funded, quasi-autonomous and non-governmental.

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Cover Photograph: Exposures of 'Second Grit' in banks of River Derwent, Shotley Bridge.

Lists of sites in this document have been compiled from previous reviews of the area's geology, published literature sources, BGS archives etc. Sites have been selected for their representativeness and geological merits. Their listing implies no rights of access. In all instances access must be arranged in advance with the appropriate land owner.

Design & Print Services, Durham County Council.

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Making a difference where you live

Thanks go to the following organisations and societies who have been consulted during the compilation of this Audit:

Durham County Council

Cumbria County Council

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The North Pennines AONB Partnership

Yorkshire Geological Society

North East Geological Society

Natural History Society of Northumbria (Geology Section)

Russell Society (Northern Branch)

Open University Geological Society (NE Branch)

Department of Geological Sciences, University of Durham

Cumbria RIGS

Cumbria Wildlife Trust

Northumberland Wildlife Trust

Durham Wildlife Trust

North Pennines Heritage Trust

Friends of Killhope

Weardale Society

Weardale Field Studies Society

Weardale Museum

Middleton Plus

Durham Dales Mining Group

Teesdale Records Society

Teesdale Heritage Group

FOREWORD

For many hundred years County Durham has been justifiably proud of the rich variety of rocks and landform features that are found within the area. As far as is known, the word 'geologia' or 'earthly science' was coined by a former Bishop of Durham, Richard de Bury, in the fourteenth century. It is thus fitting that the County Council should have been the first local authority to produce a Geological Conservation Strategy, a document which was published in 1994.

Ten years on, this much more detailed Geological Audit of County Durham has now been written describing the range of geological features to be found within the County. In many ways it is a comparable document to the Durham Wildlife Audit which was produced in partnership with English Nature in 1995. A Geodiversity Action Plan for County Durham is currently in preparation and will be produced as an Appendix to this document.

The County is grateful to both the Aggregates Levy Sustainability Fund for financing this project and to the British Geological Survey for its excellent work in compiling the contents. In highlighting the geological importance of the County and the need for its conservation we greatly hope that the residents of County will find these documents to be both informative and interesting.

Councillor Bob Pendlebury, OBE, DL
Cabinet Member, Durham County Council

Increasing pressure on land and the environment demands a greater awareness and understanding of the dynamics of our natural world in order to deliver a sustainable environment for the future. Biodiversity, and the need for Government to recognise, audit and plan for habitat and ecology is widely accepted and enshrined in legislation. However the complementary concept of Geodiversity is only now gaining recognition.

The British Geological Survey is proud to be associated with this Audit which represents the first fully comprehensive geodiversity statement for County Durham.

David A Falvey, PhD
Executive Director, British Geological Survey

June 2004

A GUIDE TO THIS AUDIT

This document seeks to address geodiversity in its very broadest sense.

As the single most important factor in determining the county's physical characteristics and providing its abundant natural resources, the fundamental importance of the underlying geology cannot be overestimated.

Although dealing with a varied, and sometimes complex, range of issues relating to earth science, this Geodiversity Audit is not targeted solely at practitioners in earth science, but is intended as a source of information and guidance for a wide range of planning, management, conservation and interpretation interests.

At the heart of the county's geodiversity is the succession of rocks, which together comprise and characterise County Durham. To these may be added the geological structures, phenomena and processes which, over millions of years of earth history, have shaped and continue to shape them today.

This document does not seek to offer a detailed geological description of County Durham but introduces those aspects of the geology, which are essential to appreciating their importance in the county and beyond.

Part 1 serves as an introduction to the concept of geodiversity and in particular its relevance and application in County Durham.

Part 2 is a detailed evaluation of the county's geodiversity. Within each geological topic the relevant issues are addressed under a series of headings. General observations or comments of national or wider relevance are followed by comments which relate specifically to the county.

A small selection of key references is given for each topic. These are mainly major reviews or syntheses of the area's geology which present the most easily accessible overview of the topic under which they are listed. Comprehensive literature references are to be found within the texts cited.

In preparing this document the use of technical jargon has been kept to a minimum, though the use of some geological terms is unavoidable in places. To assist readers unfamiliar with such terms a glossary is provided.

In the pages which follow the terms 'earth science' and 'geology' are taken to embrace the widest spectrum of earth science disciplines, including geology, palaeontology, mineralogy, geochemistry, geophysics and geomorphology.

Part 1: Geodiversity

Defining Geodiversity

Geodiversity has been defined as *"the link between people, landscape and their culture: it is the variety of geological environments, phenomena and processes that make those landscapes, rocks, minerals, fossils and soils which provide the framework for life on earth"* (Stanley, 2001), or as *"geological diversity or the variety of rocks, fossils and minerals and natural processes"* (Prosser, 2002). Highlighting a key element in Stanley's definition, Burek (2001) commented that *"Geodiversity underpins biodiversity"* and offered a further definition of geodiversity as *"the abiotic factors, which together with biodiversity give a holistic view of the landscape"* (Burek, 2002). The rapidly evolving subject of geodiversity is reviewed in detail in a book by Gray (2003), published during the final stages of the present study.

Geodiversity is a key component of an area's natural heritage. A vital starting point is an appreciation of the most up to date available understanding of the area's geological deposits and features, together with the processes and phenomena which have formed them and continue to influence them. An area's geodiversity thus encompasses:

- The historical legacy of research within the area
- Sites or features at which representative examples of the area's geological deposits and features may be seen
- Sites or features which are deemed worthy of some form of designation or protection for the quality of earth science features displayed
- The whereabouts and nature of past and present working of mineral products
- Sites and features currently employed in interpreting earth science
- The influence of earth science in shaping the built and man-made environment
- Materials collections and site and other records
- Published literature and maps
- The inter-relationship and inter-dependence between earth science and other interests

Following the UK government's ratification of the UN Convention on Biological Diversity, which resulted from the Rio Earth Summit in 1992, and the production in 1995 of the UK Biodiversity Steering Group's Report "Meeting the Rio Challenge", subsequent years have seen the preparation and implementation of Biodiversity Action Plans for most parts of the UK. Biodiversity is now accepted as an essential element in sustainable planning and management strategies.

Until recently the parallel concept of geodiversity has attracted little interest, despite its fundamental importance in underpinning biodiversity.

It is a common misconception that geological and landscape features, other than those already afforded some measure of protection as Sites of Special Scientific Interest (SSSIs), are sufficiently robust not to require active management or action planning. All geological features are potentially vulnerable. In addition to obvious threats posed by inappropriate site development and the infilling of quarries, the encroachment of vegetation, natural weathering and general deterioration with time may threaten to damage or obliterate important geological features. This situation would not be tolerated in wildlife or archaeological sites of comparable scientific or educational value.

However, geodiversity is not, or should not be, regarded merely as concerned with conservation of geological sites or features. As an essential part of natural heritage it influences fields as varied as economic development and historical and cultural heritage.

The Relevance of Geodiversity

Geology is fundamental to almost every aspect of life. Geological resources provide the raw materials for civilisation, be they fuels, water supply, metal ores or bulk and industrial minerals and building materials. A clear understanding of geology is vital to the design and siting of buildings, roads, railways and airports as well as to the safe control of waste disposal, and the management of a wide range of natural and man-made natural hazards. All are aspects of geodiversity.

The recognition of natural and cultural heritage features and their sustainable management, are today accepted as important functions within a civilised society.

The importance of the range and diversity of earth science features – the 'geodiversity' - of any area is as important a facet of its natural heritage as its wildlife interests. Conservation, sustainable management, educational use and interpretation of geodiversity is thus as important as that of biodiversity or archaeology.

Geodiversity may be one of the most significant areas of heritage interest in areas of high landscape value, or areas previously or currently affected by significant mineral extraction.

Geodiversity interests need to be integrated into management and conservation strategies for related or parallel interests, including wildlife and archaeological features.

Geodiversity issues may contribute significantly to informing a wide range of planning and environmental policies.

An appreciation of geodiversity is important to a full understanding of many aspects of biodiversity.

It also offers very substantial opportunities to enhance the conservation, management, educational use and interpretation of such related features.

Geodiversity is an emerging field, which has hitherto received little serious consideration; it needs to be embraced by all concerned with the county's heritage.

Aims and Objectives of this Geodiversity Audit

The principal aim of this Geodiversity Audit is to review the component elements of the county's geodiversity, and their relevance to other interests, in their local, regional, national and international context. It will serve as a means of informing sustainable management, planning, conservation and interpretation of all aspects of the earth science heritage of County Durham well into the future.

The Audit will also serve as the essential background to the Local Geodiversity Action Plan (LGAP), which will frame recommendations, action points and policies relevant to all aspects of geodiversity within the county.

Such recommendations, action points and policies can only be meaningful if they are based upon a sound modern understanding of the earth science of County Durham. Accordingly, in this document the key elements of the county's geology are outlined in sufficient detail to enable users who may not be trained earth scientists, or who may be unfamiliar with the geology of County Durham, to appreciate the relevance and contribution each element makes to the geodiversity of the county.

Local and regional knowledge in the field of earth sciences is often scarce in local government departments despite the fact that there may be local community interest and concern with issues relating to earth heritage. As the results of the geological audit are intended to serve as an important guide and source of reference well into the future they are presented here as a separate document. Specific recommendations and action points derived from this audit will be published separately and will include the results of consultation with a wide range of interested parties.

Individual objectives within this Geodiversity Audit may be summarised thus:

- To raise awareness of the fundamental importance of geodiversity in County Durham
- To improve knowledge and understanding of the geodiversity of County Durham
- To identify the main geological formations and features, and to evaluate their contribution to geodiversity within County Durham.
- To place these geological formations and features in their regional, national and, where appropriate, international context.
- To provide non-specialists with an easy to use guide to the geodiversity of County Durham.
- To identify linkages between the county's geodiversity and its landscape character, biodiversity, economic and cultural history.
- To comment on geodiversity issues relevant to planning, development, mineral extraction and environmental monitoring and management.
- To identify threats to geological features.
- To identify opportunities to enhance the value of geological features.
- To evaluate those geological sites within the county which currently enjoy statutory protection as Sites of Special Scientific Interest (SSSIs), and non-statutory protection as Durham County Geological Sites (DCGS) or Regionally Important Geological and Geomorphological Sites (RIGS), of which there is only one at present in Durham.
- To encourage industry, local communities and voluntary groups and societies to become involved in understanding and celebrating the county's geodiversity.
- To 'embed' geodiversity into future planning, management and interpretation policies.
- To provide a sound expert basis for framing specific recommendations and action points for the county's geodiversity

The influence of Geology in County Durham

County Durham comprises approximately 223,106 hectares of North-East England extending from some of the highest ground of the Northern Pennines, eastwards to the North Sea coast (*Figure 1*).

In the mid 1990's the then Countryside Commission and English Nature developed a joint project to map variations in the landscape and ecological characteristics of the English Countryside. The result of this collaboration was a joint map, called 'The Character of England: landscape, wildlife and natural features', which identifies 181 Countryside Character Areas and 120 Natural Areas. Natural areas are broad bio-geographic zones. Countryside Character Areas are broad regional landscapes. Together they form a national framework for decision making about landscape and biodiversity.

It is a reflection of the great scenic diversity of County Durham that it includes six Countryside Character Areas and five Natural Areas (*Figure 3*). The Northumbria Coal Measures Natural area is subdivided into two Character Areas; the remaining four Natural areas correspond to the four Character areas and are known as 'Joint Character Areas'. The structure of these broad

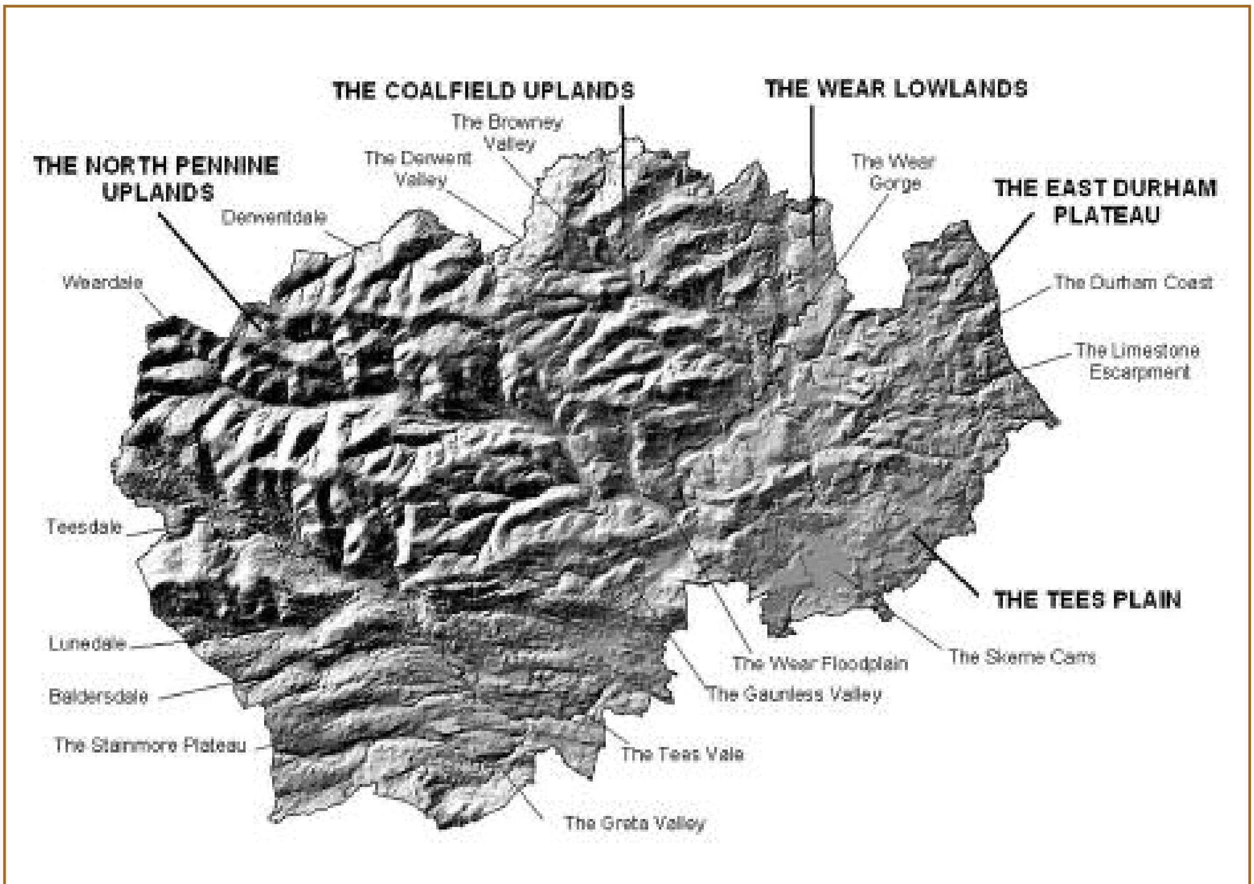


Figure 1. The Topography of County Durham

landscapes strongly reflects the underlying geology (*Figure 2*).

The Pennine uplands which attain 746 metres at the county's highest point, Burnhope Seat, and which include the headwaters of the rivers Derwent, Wear and Tees, lie within the North Pennines character area. Within the county, much of this coincides with the North Pennines Area of Outstanding Natural Beauty, now designated as Great Britain's first European Geopark (*see page 9*).

Together with the county's great biological, economic and cultural diversity, these varied landscapes closely reflect the underlying geodiversity. In few areas of Great Britain can the inter-relationships, inter-dependence and relevance of geology with all of these other factors be more clearly demonstrated than in County Durham.

The fundamental importance of geology is perhaps most obvious in its role in shaping the physical landscape. The scenic landscapes of the valleys of the River Wear and its tributaries are now designated as Areas of High Landscape Value in development plans. The form, pattern and character of the hills, valleys and coast are profoundly influenced by the geological materials of which they are composed, and by the complex interplay of earth processes which have shaped them over millions of years of geological time.

The essential part played by geology in shaping this landscape extends far beyond the creation of landforms. Ecology is directly dependent upon soils and climate. Soils derive many of their most fundamental characteristics from their parent materials – the underlying rocks or other geological deposits. The close, often intimate, relationship between vegetation and the

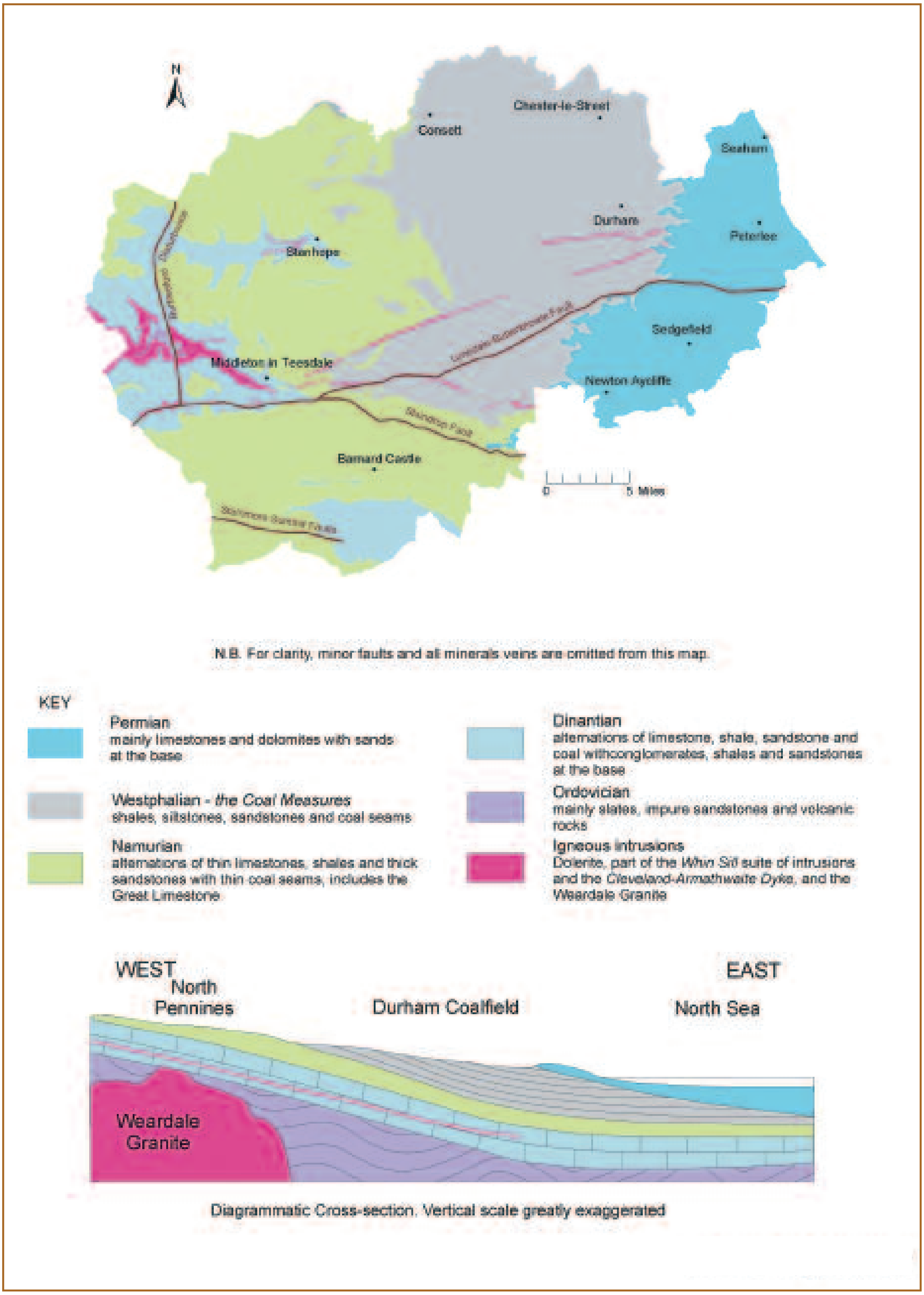


Figure 2. Simplified geological map of County Durham

underlying geology is everywhere an important factor in understanding the ecology of the county. These same ecological considerations direct and constrain land use practices, be they hill pastures, grouse moors, forestry or agriculture. The crucial link between geodiversity and biodiversity are thus both obvious and inescapable: an appreciation of one is essential to the true understanding of the other.

The diversity of geological materials within the county has long offered a wealth of raw materials. An abundance of rocks suitable for building have, through their individual and distinctive properties, helped create the characteristic local vernacular architecture. Farm buildings, hamlets and villages and, in the upland parts of the county, countless miles of drystone walls, clearly reflect the local geology. Even in towns the traditional use of stone and locally made brick impose a distinctive character on architecture and hence the urban landscape. County Durham's most famous building and World Heritage Site, Durham Cathedral, stands as an eloquent testimony to the use of locally won Coal Measures sandstone.

The same diverse geology provided the raw materials for the extractive industries, which for centuries formed the basis of much of the county's economy. County Durham is inextricably linked to coal mining, an industry which, until the second part of the 20th century, was the county's largest employer. Over the centuries, millions of tons of Durham coal fuelled industries, railways and shipping locally and across the world. Underground coal mining in the county has now ended. Opencast extraction continues, currently at one site.

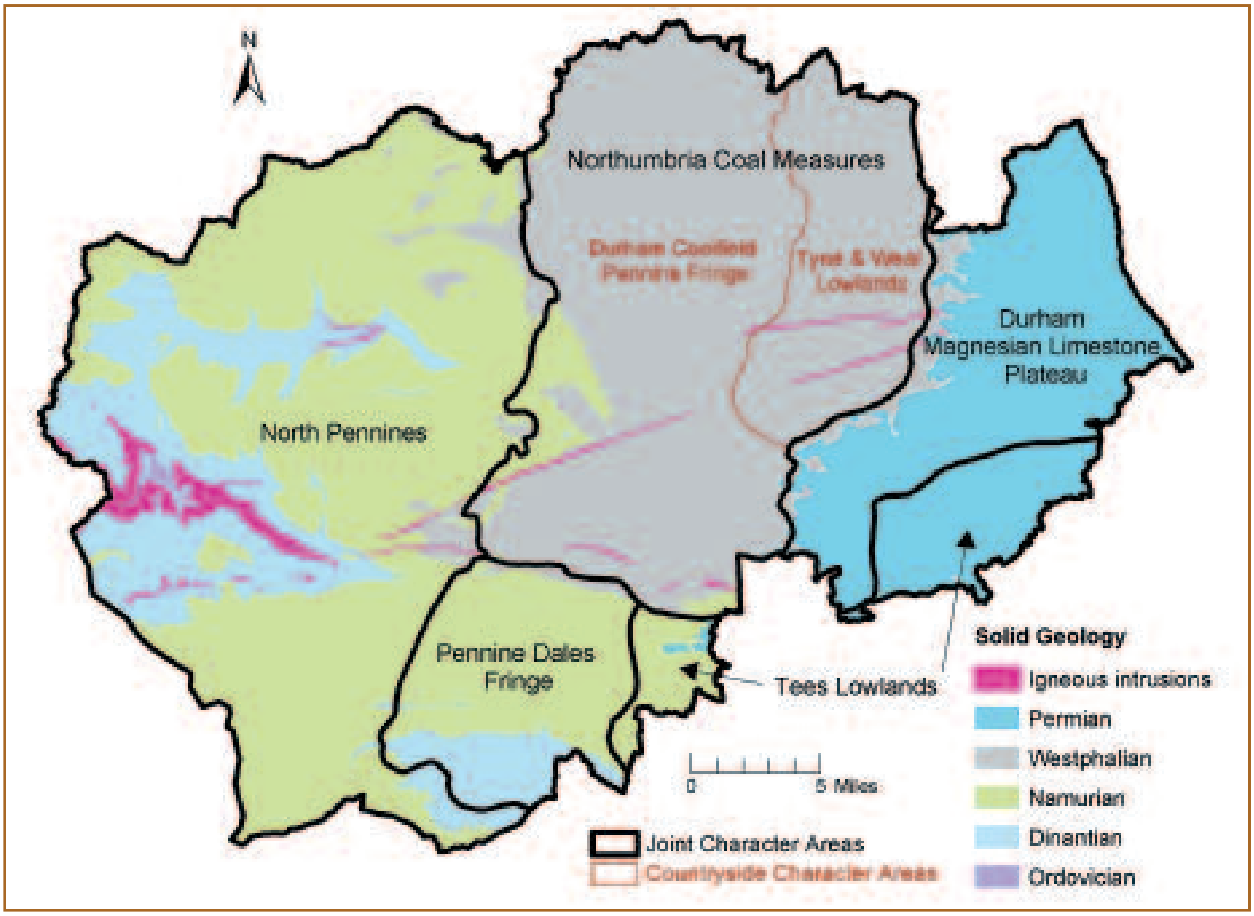


Figure 3. English Nature 'Character Areas' within County Durham

County Durham also has a long and distinguished history as a major source of lead and iron ores, mined from the Pennine hills and dales in the west of the county. Small, but significant, amounts of silver were recovered as a by-product of lead mining and smelting. The demise of lead mining in the late 19th century was accompanied by the emergence of ready markets for the spar minerals fluorspar, barytes and witherite. County Durham led the world in production of fluorspar and shared with its neighbour Northumberland the distinction of being the world's chief commercial source of witherite. Although mining of these minerals has ended within the county, further reserves, particularly of fluorspar, may exist but must await a more favourable economic climate to attract commercial interest.

The county has long been a major source of sandstone, limestone, dolomite, dolerite ('whinstone'), sand and gravel, brick and refractory clays. All are still produced within the county.

Centuries of exploitation have left an almost universal and indelible imprint on the county's landscape. Although mineral extraction is today a shadow of its past, it remains an essential element in the human and economic profile of the area. The past, present and future use of geological materials, and the interdependence of economic and cultural factors with the exploitation of these natural resources, are essential elements in the county's geodiversity.

Through its long history of mineral extraction, the county has been at the forefront of developing ideas and concepts in the understanding of geological materials and processes. Research on County Durham's geology has made major contributions to many avenues of earth science. Of particular note are those relating to the understanding of coal and coal-bearing rocks, the marine Permian rocks of eastern County Durham, the nature and origins of the Whin Sill and the range of geological, geophysical and mineralogical studies of the nature and formation of the Pennine ore deposits. All have made significant impacts upon similar rocks and features worldwide. This historical legacy is another factor in the rich geodiversity of the area. The county remains, and will long continue to be, an important educational and research resource in a varied range of earth science fields.

Conserving Earth Science within County Durham

The word 'geology' can trace its origins back to Durham in the 14th century, although as originally coined the word had a much wider meaning than that understood today.

The word 'geologia' was first used by Richard de Bury, Bishop of Durham between 1333 and 1345. In his book '*The Philobiblion*' he discusses laws, arts and sciences and in so doing introduces the new term **geologia** or **earthly science**.

"…From which it is seen clearly enough, that as laws are neither arts nor sciences, so books of law cannot properly be called books of art or science. Nor is this faculty which we may call by a special term geologia or the earthly science, to be properly numbered among the sciences. Now the books of the liberal arts are so useful to the divine writings, that without their aid the intellect would vainly aspire to understand them…" (Translation from the Latin of *The Philobiblion*.)

Following on from this early recognition of the importance of 'earthly science', County Durham has a long and distinguished record in addressing those aspects of management and conservation of geological features which are today included within the term geodiversity. An understanding of the nature and scope of existing conservation measures is an essential basis for informing proposals and recommendations for future sustainable management, conservation and interpretation of the county's geodiversity.

The extremely varied natural and cultural landscape of County Durham includes a wealth of earth science features and sites which not only contribute to the distinctive character of the county, but which also have an interest and importance which extends beyond its boundaries. Such features may be recognised in a number of ways. This may take the form of legal protection through statutory scheduling as National Nature Reserves (NNRs) or as Sites of Scientific Interest (SSSIs), through non-statutory designation as Durham County Geological Sites, or as most recently, by the recognition of the entire North Pennines Area of Outstanding Natural Beauty (AONB) as a European Geopark.

The North Pennines AONB European Geopark

The North Pennines AONB covers much of the west of County Durham together with parts of Northumberland and Cumbria (*see Figure 4*). The primary purpose of AONB designation is to conserve and enhance natural beauty. 'Natural Beauty' in this context *"…is acknowledged to refer to a meeting of scenic, ecological, physiographical, geological and cultural interests, which help to define the special characteristics of a particular place"* (North Pennines AONB Management Plan, 2004).

The important role played by geology in shaping the physical and human character of the North

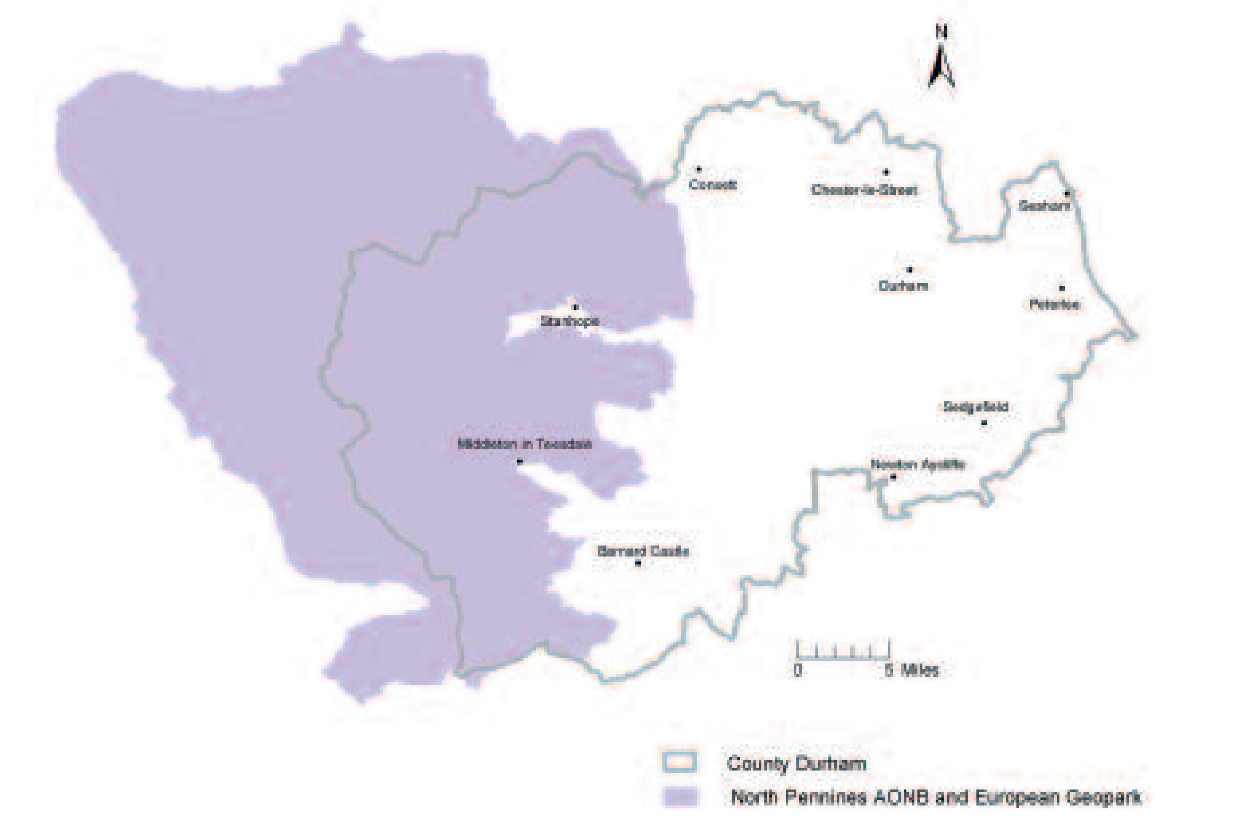


Figure 4. County Durham and the North Pennines Area of Outstanding Natural Beauty

Pennines, and its potential for interpretation, education and research, was recognised in June 2003 by the designation of the North Pennines AONB as a European Geopark, the first on the UK mainland. A European Geopark is a defined territory with a specific geological heritage, where there is considerable local effort to conserve this heritage and encourage its enjoyment and understanding by a wide public. UNESCO is soon to establish a 'Global Geopark' network, with the 17 existing European Geoparks, including the North Pennines AONB, and thus a substantial portion of County Durham, at the forefront of this new world-wide designation.

Statutory designations protecting the earth science interest of County Durham

National Nature Reserves (NNRs)

National Nature Reserves represent some of the best wildlife and earth heritage sites in the country, many of which are important in an international context. There are six National Nature Reserves in County Durham including part of the extensive Moorhouse - Upper Teesdale NNR, which is designated as an International Biosphere Reserve by UNESCO (United Nations Educational, Scientific and Cultural Organisation), the first to be established in the United Kingdom.

The Moorhouse - Upper Teesdale NNR incorporates numerous features of earth science significance, including classic outcrops of the Whin Sill, its contact metamorphic rocks including the 'Sugar Limestone', significant occurrences of mineralisation, and extensive and internationally important expanses of blanket bog. It is also internationally celebrated for a range of extremely important and rare biological habitats. It offers superb opportunities to demonstrate the vital and intimate relationship between the area's geodiversity and its biodiversity.

Derwent Gorge and Muggleswick Woods NNR is a ravine woodland which is one of the finest and largest remaining oakwoods in North-East England. It occupies a spectacular meander of the River Derwent deeply incised into Namurian rocks with remnants of former lead mining operations.

Castle Eden Dene NNR comprises the largest, and perhaps finest, of the Durham denes. These are deeply incised valleys cut through Quaternary deposits into the underlying Magnesian Limestone. Although Castle Eden is designated as an NNR primarily for its woodland ecology, it is an important geological feature and contains numerous important individual sites of geological interest.

Thrislington NNR is an outstanding example of Magnesian Limestone grassland which here supports a variety of scarce plant species. The reserve includes areas of grassland successfully transplanted as giant turves in advance of limestone extraction at the adjoining Thrislington Quarry.

Cassop Vale NNR is designated for its fine examples of Magnesian Limestone grassland, scrub and woodland. In addition, the reserve includes good examples of valley bottom fen and swamp vegetation as well as re-colonised spoil heaps of a long-abandoned coal mine.

The Durham Coast NNR includes striking examples of Magnesian Limestone cliffs, headlands and beaches, together with the seaward ends of the deeply incised denes carved by glacial meltwaters. In addition to important sections through the Magnesian Limestone, there are good sections through the overlying Quaternary deposits. The reserve also features notable Magnesian Limestone grassland plant communities.

Sites of Special Scientific Interest (SSSIs)

The very best of the country's wildlife and geological sites enjoy legal protection through their designation as SSSIs. This designation was introduced as one of the provisions of the 1949 National Parks & Access to the Countryside Act and has been maintained through subsequent conservation legislation. The network of SSSIs in England is the responsibility of English Nature.

County Durham contains a number of SSSIs notified primarily for their geological importance. In addition, many of the SSSIs notified for other interest include features of geological significance.

Geological Conservation Review (GCR) Sites

The Geological Conservation Review (GCR) was initiated by the Nature Conservancy Council in 1977 to identify, assess, document and eventually publish accounts of the most important parts of Great Britain's rich and varied geological heritage. GCR sites are those of national or international importance which have either been notified as SSSIs or are being considered for such notification. Publication of descriptions of GCR sites is being undertaken in a series of 42 thematic volumes. Since 1991, publication of descriptions of GCR sites has been undertaken by the Joint Nature Conservation Committee on behalf of the three country agencies, English Nature, Scottish Natural Heritage, and the Countryside Council for Wales.

County Durham includes a number of GCR sites.

Non-statutory designations protecting the earth science interest of County Durham

Regionally Important Geological and Geomorphological Sites (RIGS)

Regionally Important Geological and Geomorphological Sites are *"any geological or geomorphological sites, excluding SSSIs, in a county …that are considered worthy of protection for their educational, research, historical or aesthetic importance"*. RIGS are broadly analagous to non-statutory wildlife sites and are often referred to locally by the same name. They can include important teaching sites, wildlife trust reserves, Local Nature Reserves and a wide variety of other sites. RIGS are not regarded as 'understudy' SSSIs, but as sites of regional importance in their own right. Although these are non-statutory designations, the sites are recognised by the local planning authorities.

RIGS groups are organised locally, most commonly with a predominantly amateur membership. As the RIGS scheme is mainly dependent on volunteer effort its coverage tends to reflect local enthusiasm and is thus rather patchy.

Moking Hurth, or Teesdale, Cave is the only locality within County Durham designated as a RIGS. Attempts to establish an active RIGS Group for County Durham have so far been unsuccessful.

Durham County Conservation Trust sites

The draft National Scheme for Geological Site Documentation, prepared originally in 1975 by the Nature Conservancy Council and the Geological Curators' Group, further developed by the latter group and the Information Retrieval Group of the Museums Association, was devised to encourage recording of geological sites as an important tool to inform and facilitate geological conservation. In responding to this initiative, between 1977-78, Durham County Conservation Trust (the precursor to Durham Wildlife Trust) undertook one of the first comprehensive surveys of geological sites to be undertaken by a County Trust. The project aimed to provide the information necessary to further the effective conservation of geological sites, to facilitate monitoring of those sites and, where appropriate, to recommend sites for notification as SSSIs. The study culminated in the publication of the document "Significant geological exposures in the Tyne to Tees area" (Durham County Conservation Trust 1978). This identified and listed sites at which significant, or representative, exposures of named geological units or formations known within the county could be seen.

For each of the sites identified, details including geological features exposed and condition of the site at the time of the field visit were recorded. In addition, each site was assigned a rating to reflect such factors as its geological merits, accessibility, and vulnerability. The information collected during the study is today held at the Hancock Museum, Newcastle upon Tyne.

Although the sites so identified were accorded no protection, the exercise marked an extremely important first step in assessing the scope of the geological resources of County Durham.

Durham County Geological Sites (DCGS)

The Geological Conservation Strategy, published by Durham County Council in 1994, was devised to be a natural sequel to the Durham County Conservation Strategy. This involved a major review of the most significant sites representative of the county's geology and geomorphology. The work was undertaken with the advice and assistance of local geological experts who identified a network of candidate Durham County Geological Sites (DCGS). It may be seen as building upon, and updating, the principles that lay behind the 1978 report. Like this report, the County Geological Strategy broke new ground. It was the first geological strategy produced by a local authority and is believed to remain one of the few such exercises undertaken.

The first County Geological Sites were approved by the Environmental Committee of the County Council in April 1993. Although these are non-statutory designations, the sites are recognised by the local planning authorities who consult Durham County Council over proposals which may affect them.

The County Durham Geological Conservation Strategy includes the following three non-development plan policies:

CGS 1 Maintenance of List of County Geological/Geomorphological Sites

> *"The County Council, aided by expert opinion, will prepare a list of important geological and geomorphological sites in County Durham. The list will be maintained by the County Council and reviewed periodically in consultation with local experts".*

CGS 2 Site Creation

> *"The County Council will promote the creation of new geological sites at scientifically important horizons during the construction of major developments such as road building and improvements".*

CGS 3 Education

> *"The County Council will assist in identifying and promoting suitable geological and geomorphological sites for teaching purposes".*

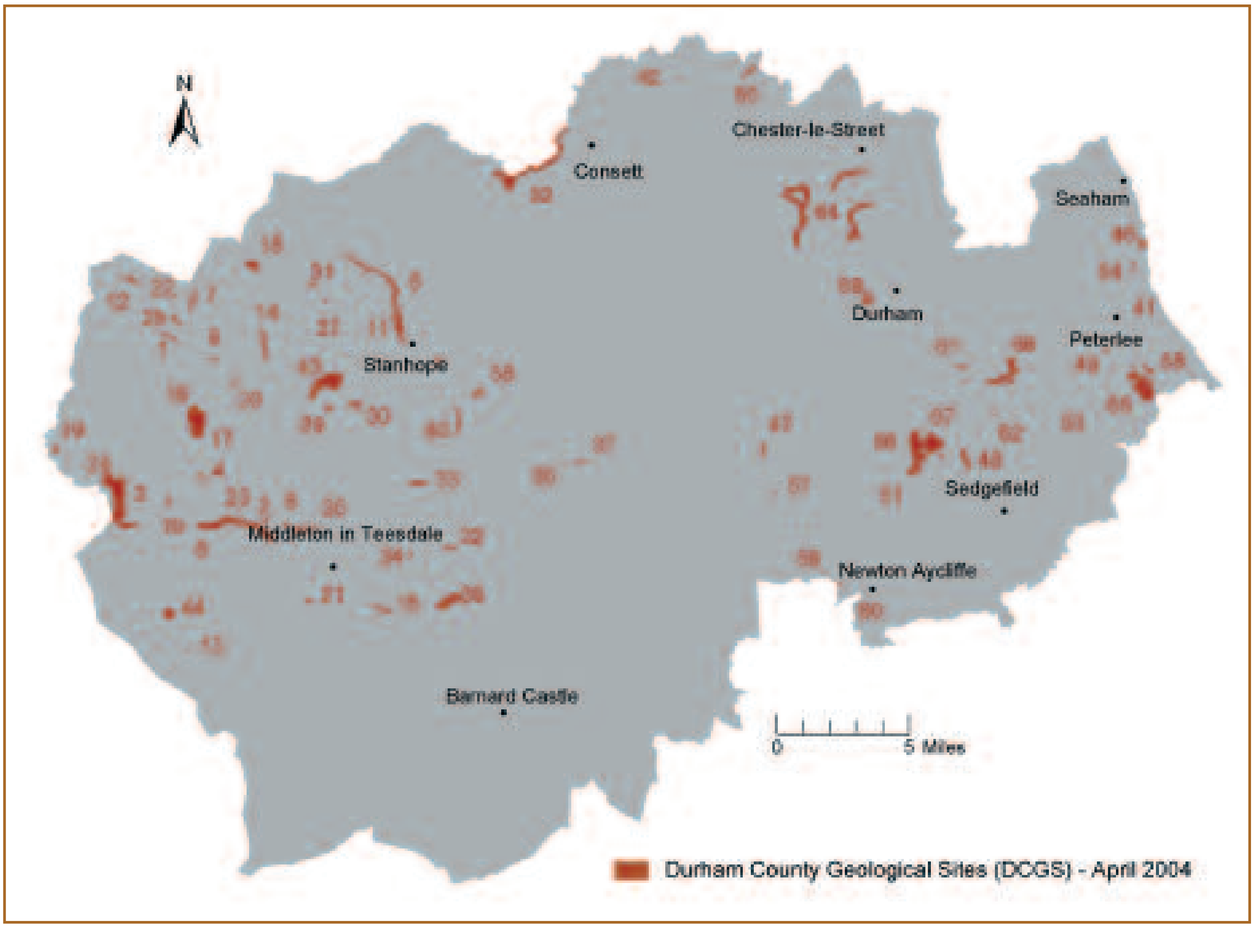


Figure 5. Location of Durham County Geological sites (April 2004)

Table 1. Details of County Durham County Geological Sites shown in Figure 5.

Details of Durham County Geological Sites shown on Figure 5 (A number of originally designated sites lie outside the current county administrative area)

1 Black Cleugh, Burnhope - (Dinantian + Structure)
2 Wynch Bridge - (Minerals + Igneous)
3 Widdybank Fell - (Igneous + Metamorphic)
4 Teesdale Cave (Moking Hurth Cave) - (Karst)
5 Stanhope Burn - (Dinantian, Namurian + Minerals)
6 Stable Edge Quarry - (Namurian)
7 Sedling Burn, Cowshill, Weardale - (Dinantian, Namurian + Minerals)
8 Scoberry Bridge to Dine Holm Scar (River Tees) - (Igneous, Metamorphic + Landform)
9 St. Johns Chapel Drumlins - (Landforms)
10 Pencil Mill - (Ordovician)
11 Noah's Ark Quarry - (Minerals)
12 Killhope Wheel Lead Mining Centre - (Minerals + Namurian)
13 Hunters Vein - (Minerals)
14 Middlehope Burn - (Minerals + Dinantian)
15 Holwick Drumlins, Romaldkirk - (Landforms)
16 Harthope Quarry - (Namurian + Palaeontology)
17 Harthope Head Quarries - (Namurian)
18 Grove Rake Mine and Opencast - (Minerals)
19 Greenhurth Mine - (Minerals)
20 Greenlaws Mine - (Minerals, Dinantian + Palaeontology)
21 Green Gates Quarry - (Dinantian + Metamorphic)
22 Greenfield Quarry, Cowshill - (Palaeontology)
23 Dirt Pit Mine - (Minerals)
24 Cow Green Mine - (Minerals + Metamorphic)
25 Copthill Quarry, Killhope Burn and Wear River at Burtreeford Bridge - (Structure, Igneous + Dinantian)

26 Coldberry Gutter - (Minerals, Igneous + Namurian)
27 Chestergarth Quarry, Rookhope - (Namurian + Palaeontology)
28 Bow Lees Beck - (Dinantian, Palaeontology + Karst)
29 Bollihope and Snowhope Carrs (Snowhope Carrs) - (Landforms + Quaternary)
30 Bollihope and Snowhope Carrs (Bollihope Carrs) - (Landforms + Quaternary)
31 Boltsburn Mine and Rookhope Borehole - (Minerals + Igneous)
32 Spurlswood Beck and Quarter Burn, Eggleston - (Namurian-Westphalian contact + Palaeontology)
33 Sharnberry Meltwater Channel - (Landform)
34 Knott's Hole Meltwater Channel (associated with Sharnberry MC) - (Landform)
35 Roundhill Quarry, Stanhope - (Namurian)
36 Knotty Hills and Hoppyland Kames (Hoppyland Kames) - (Landforms)
37 Knotty Hills and Hoppyland Kames (Knotty Hills) - (Landforms)
38 Harehope Quarry, Frosterley - (Namurian, Palaeontology, Buildings + Minerals)
39 Folly House Glacial Drainage Channels, Eggleston - (Landforms)
40 Fine Burn, Bollihope - (Namurian)
41 Dene Holme - (Permian)
42 Craghead Crags, Lintzford - (Westphalian)
43 Cement Works Quarry, Eastgate - (Namurian + Karst)
46 Beacon Hill Rail Cutting - (Permian + Palaeontology)
47 Binchester Crags - (Westphalian)
48 Bishop Middleham Quarry - (Permian)
49 Castle Eden Dene - (Permian + Landforms)
50 Causey Burn - (Westphalian)
51 Chilton Quarry - (Minerals + Permian)
52 Derwent River Gorge - (Namurian)
53 Dropswell Farm, NNE Hillside - (Permian + Tufa)
54 Underground tunnels at Easington Colliery - (Westphalian + Mining)
56 Ferryhill Gap - (Permian + Landforms)
57 Gaunless River - (Westphalian)
58 Hesleden Dene and downstream continuation (HD) - (Permian + Landforms)
59 Middridge railway cutting - (Westphalian)
61 Old Quarrington Quarry - (Permian)
62 Raisby Railway Cutting - (Permian + Minerals)
63 Rough Furze Quarry - (Permian + Minerals)
64 Sacriston Subglacial Channels - (Landforms + Quaternary Deposits)
65 Part of Sheraton Kame moraine - (Landforms + Quaternary Deposits)
67 Thrislington Quarry - (Permian + Palaeontology)
69 Wear River Gorge at Durham City - (Landforms, Westphalian + Buildings)

County Wildlife Sites

The network of County Wildlife Sites within County Durham does not have any sites designated primarily for their earth science interest, although features of earth science importance may be present.

Although these are non-statutory designations, the sites are recognised by the local planning authorities who consult the County Council over proposals which may affect them.

Some of these sites offer excellent opportunities for an integrated approach to conservation and interpretation of natural heritage.

Do protected sites adequately represent the geodiversity of County Durham?

As SSSIs and GCR sites within County Durham have been selected to reflect the national or regional importance of the features exposed they do not necessarily provide a representative coverage of the county's geology.

The network of Durham County Geological Sites was devised to provide that representative coverage. This audit of the county's geology has demonstrated that the existing Durham County Geological Sites are still relevant. However, in the light of this detailed evaluation of the county's geology, and the need to make provision for future conservation, management and interpretation of the key elements of this geology, some additional sites are desirable. Recommendations for these will be included in the Geodiversity Action Plan.

Opportunities to enhance understanding of geological features in County Durham

Many types of groundworks and civil engineering, particularly road building and improvement works may involve significant excavation. Such operations offer opportunities to reveal hitherto unexposed geological sections, either temporarily during construction, or as permanent features. Geological features exposed in cuttings may be viewed as assets which contribute to the county's natural heritage. It is common practice in road construction to cover rock exposures in excavations, particularly cuttings, thus permanently obliterating potentially important geological exposures. With careful and imaginative planning such exposures could be retained as interesting and instructive landscape features with considerable educational value.

Quarries, both working and abandoned, offer prime opportunities to see exposures of rocks and geological features. Restoration or reclamation of abandoned quarries, landfilling, or landscaping of spoil heaps, may threaten to damage or destroy important geological features. Careful and imaginative planning, involving liaison with owners and quarry operators, may not only allow preservation of these features, but also may offer opportunities to create interesting and valuable landscape features or educational resources. This may include provision for various forms of access.

Crucial to safeguarding any such features is the knowledge of what is present and an understanding of the local, regional or national, significance of those features. One of the key purposes of this Geodiversity Audit is to inform this process of understanding and to heighten awareness of the importance of taking geological interests into account in a wide range of planning and development issues.

Earth science interest of sites protected for other reasons

Sites of Special Scientific Interest (SSSIs)

Most of the SSSIs within the county are designated for their wildlife interest. Some parallel earth science interest may be identified at a number of these, for example, where distinctive plant communities are related to particular rock types. Such sites offer excellent opportunities for an integrated approach to conservation and interpretation of natural heritage.

Scheduled Ancient Monuments (SAMs)

A number of sites of former extractive industries within the county are designated as Scheduled Ancient Monuments for their industrial archaeological interest. SAM status is a statutory designation that imposes certain legal restrictions on activities which may be permitted at a site.

Focussing upon archaeological considerations, the scheduling does not normally take into account the often intimately associated nature conservation, including earth science, interests. As may be expected of former mines or quarries, a number of these sites encompass features of some earth science importance.

Lead Mining Sites

The report *"The North Pennines Lead Industry; Key sites and proposals for action"* (North Pennines AONB Partnership - 2001), reviews the remains of the North Pennines lead industry and its impact upon the landscape. Several of the sites listed lie within County Durham. As with SAMs (above), no account is taken of the earth science interest, though many lead mining sites within the county include features of earth science importance.

Amongst the report's recommendations are lists of sites of former mineral working identified as meriting conservation and public access. As it is likely that the conservation, enhancement, public access or interpretation measures proposed for many of these sites may require some on-site groundworks, it is important to identify and make appropriate provision to safeguard the features of key earth science interest.

Can other conservation interests threaten earth science features?

Sites or features selected for any form of protection can rarely, if ever, be satisfactorily regarded as 'single interest' sites. Statutory designations, for example as SSSIs or SAMs, offer powerful means of protecting the most important sites and features, though even here failure to take account of other interests can lead to misunderstandings and potential conflict. In some instances scheduling without adequate multi-disciplinary consultation may even result in these related interests being put at risk. Non-statutory designations, whilst offering no legal protection may, nevertheless, be extremely useful in highlighting a site's importance. However, here again, the 'claiming' of such a site by one interest group, without an awareness of other likely interests, may act against the best conservation of that site.

In some instances the legal restrictions associated with SAMs may be detrimental to the conservation and use of the site's earth science interest. For example, a mine site selected for conservation and restoration of its archaeological interest may also include extremely important geological features. Failure to take these into account may result in them being compromised or even destroyed. There is thus a need wherever possible to eliminate the potential for any conflict between different conservation interests.

Opportunities to enhance the value or interest of other protected sites

The incorporation of some explanation of relevant geological information could greatly enhance the understanding of the archaeological or wildlife features visible at abandoned limestone quarries and limekilns or lead mine sites. Comment on the nature and use of building materials can greatly enhance the appreciation of the built heritage.

A multi-disciplinary approach to conservation of <u>all</u> features, is not only highly desirable, but offers enormous potential to enhance the value and interest of many individual sites. Whereas this may seem obvious, the underlying principle seems often to have been overlooked, or even ignored, in many previous conservation initiatives.

Selected References

Burek, 2001; Burek and Potter, 2002; Durham County Conservation Trust, 1978; Durham County Council, 1994; Ellis, 1996; English Nature et al. 2003; English Nature, 1991, 2000, 2002, 2003; Gray, 2003; Nature Conservancy Council, 1990; North Pennines AONB Partnership, 2004a, 2004b; Prosser, 2002; Stanley, 2001.

Part 2: The Geodiversity of County Durham

THE GEOLOGICAL RESOURCE

THE GEOLOGICAL EVOLUTION OF COUNTY DURHAM

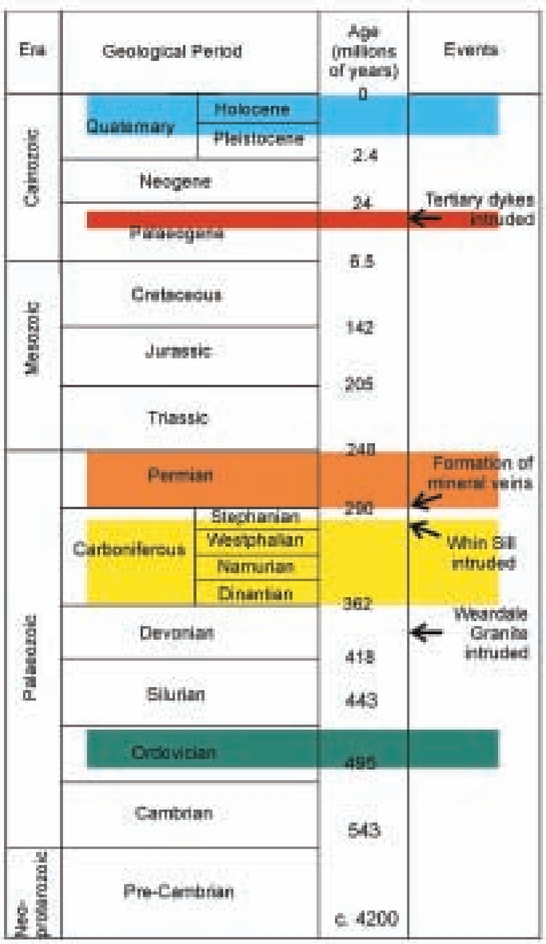
Before embarking upon a detailed exploration of County Durham's geodiversity, and in order to help view the rocks in their true context, it is worth very briefly considering the main events which have shaped the county. A detailed discussion of the geological evolution of County Durham is not appropriate here: good accounts can be found in the literature references cited below.

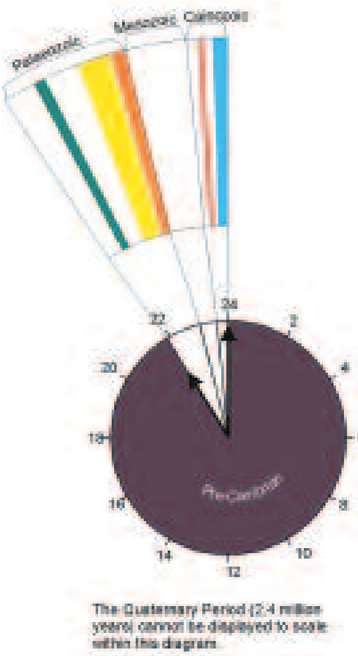
The diversity of County Durham's rocks, their composition, structure, the fossils and minerals they contain, and the processes which have shaped, and continue to shape them, enable geologists to decipher the history and evolution of the county. It is a story which can be traced back over almost 500 million years.

Figure 6. Simplified geological timescale of County Durham

Geologists divide time into three Eras, each of which is subdivided into Periods. By combining evidence from successions of rocks with the more or less precise ages for some of these rocks, obtained by sophisticated analytical methods, it is possible to arrive at the geological timescale shown here. Enormous though this is, extending back over 543 million years, this represents only that part of earth history during which fossils give us evidence of life. Almost 4,000 million years of geological time are known before the beginning of the Cambrian Period.

The highlighted colour bands on the timescale indicate those periods of geological time which are represented by rocks in County Durham.





The Earth is believed to be about 4,200 million years old, an almost impossible age to imagine. A good way to grasp this is to think of the age of the Earth as a single day. On this scale the oldest rocks we see in the North Pennines formed around 10.15pm, with the rocks which make up much of the county dating from around 10.40-11.00pm. The 24 hour clock in this figure helps to put the enormity of these time periods into context.

The record, as contained in the rocks, is however incomplete. In Figure 6, which illustrates the main periods of geological time, those periods for which there is clear evidence preserved in the rocks of the county are highlighted. For much longer periods of time, the county contains no rocks and thus no direct evidence of events or conditions. For any interpretation of these periods in County Durham, we must rely upon information gathered from the rocks formed elsewhere at these times.

The oldest rocks known in County Durham date from the Ordovician period of earth history, between 495 and 443 million years ago. The configuration of landmasses across the earth was then very different from today. At this time the area which was to become North-East England lay south of the equator, where it formed part of a deep ocean, known to geologists as the Iapetus Ocean, on the northern edge of a continental plate known as Eastern Avalonia. Mud and sand, which accumulated in this ocean, are preserved today as the mudstones and sandstones of the Skiddaw Group. Eastern Avalonia was then moving gradually northwards towards another huge continent, known as Laurentia, which included what would eventually become Scotland and much of North America. Huge stresses in the earth's crust, caused by the movement of these continents, resulted in the enormous volcanic eruptions which created an enormous thickness of volcanic rocks, known as the Borrowdale Volcanic Group. As these continents finally collided, the Iapetus Ocean was destroyed, and crumpling of the rocks brought into being a new mountain chain across what is now northern England.

Associated with the creation of these mountains was the emplacement, about 410 million years ago, deep beneath the surface, of a huge body of granite known as the Weardale Granite. As we shall see this granite was to have a profound influence on the area's subsequent geological history and upon the formation of its mineral deposits.

The Ordovician rocks, which are known to underlie much of Northern England, are best seen at the surface today in the Lake District, but are also exposed along the foot of the Pennine escarpment and in a small part of Upper Teesdale, where they emerge from beneath their cover of Carboniferous and younger rocks. These areas of older rocks surrounded by younger rocks are known as the Cross Fell and Teesdale inliers respectively. Ordovician rocks have also been proved in a handful of deep boreholes in County Durham and adjoining areas.

Rocks formed during the Silurian period, between 443 and 418 million years ago, are not exposed in County Durham, though, as they are present within the Cross Fell Inlier, it is possible that such rocks may lie deeply buried beneath parts of County Durham. There are few rocks in northern England which can be reliably dated to the next period of earth history known as the Devonian period, between about 400 and 360 million years ago. However, conglomerates exposed locally on the Pennine escarpment may represent accumulations of boulders and gravels deposited amongst the eroding mountains. Representatives of these may also lie concealed beneath County Durham.

By the beginning of the Carboniferous Period, roughly 360 years ago, the area which was destined to become County Durham had moved to a position almost astride the equator. At this time much of what is today northern England began to be progressively submerged beneath a wide, shallow tropical sea, in the clear, warm waters of which beds of limestone accumulated. Periodic influxes of sand and mud, deposited by deltas building from a landmass to the north or north east, periodically established swamp or delta top environments, occasionally with the development of lush tropical forests. The evidence for these conditions is preserved today as the layers of sandstone and mudstone of the Carboniferous rocks. As Carboniferous times progressed, tropical forest cover became much more frequent, the remains of which are preserved today as the coal seams of the Coal Measures.

The Weardale Granite exerted a very strong influence on the nature of Carboniferous rocks of the developing northern England, particularly in early Carboniferous times. Granite is less dense than most rocks in the earth's crust. It is therefore rather buoyant, tending to rise relative to the rocks which surround it. Because of this, as the area which was to become the North Pennines gradually subsided at the beginning of the Carboniferous Period, the 'block' of Ordovician rocks, together with the Weardale Granite, tended to subside rather less rapidly than the surrounding areas. As a result a much thinner succession of Carboniferous limestones, mudstones and sandstones accumulated on this 'block' than in the adjoining areas. Geologists term this area the 'Alston Block'. A similar 'block', here too partly underpinned by an old granite, comprises the area known as the 'Askrigg Block' of the Yorkshire Pennines. Separating these, is the belt of much more rapid Carboniferous subsidence, and thus of much thicker Carboniferous sediments, known as the Stainmore Trough. County Durham encompasses much of the Alston Block and parts of the Stainmore Trough.

Towards the close of Carboniferous times, about 295 million years ago, continuing stretching of the earth's crust allowed the up-welling of huge volumes of molten rock from deep within the earth. This basic magma did not reach the surface, but spread out as sheets and layers between the existing Carboniferous rocks. As it cooled and crystallised to form the dolerite of the suite of intrusive rocks collectively known as the Whin Sill, its heat profoundly altered many of the adjoining rocks, turning limestone into marble, known in Teesdale as the 'Sugar Limestone' and shales into 'hornfels', or as it is known locally, 'whetstone'.

Shortly after the formation of the Whin Sill, mineral rich waters, warmed by heat from the Weardale Granite, began to circulate through cracks and faults in the rocks deep within the earth's crust. As they cooled, their dissolved minerals crystallised forming the veins and associated deposits of the North Pennine Orefield.

Major earth movements towards the end of Carboniferous times once more created mountains across what became northern England. By about 280 million years ago, during the Permian Period, the area that is today the Northern Pennines probably consisted of mountains, with valleys choked with rock debris broken from the rapidly eroding mountains. Huge wind-blown sand dunes formed in a desert, which covered much of the comparatively low ground in what is today central and eastern County Durham. These are today the 'Yellow Sands' seen in quarries in the east of the county.

This Permian desert was soon inundated by the rapidly advancing waters of a sea, known to geologists as the Zechstein Sea. This occupied an area which included that of the modern North Sea. Sediments deposited in the Zechstein Sea record repeated cycles of sea level change, in part due to periods of evaporation of substantial parts of the sea. The earliest Zechstein sediments in County Durham comprise the grey bituminous limestone known locally as the 'Marl Slate'. This comparatively thin bed is believed to have accumulated in rather stagnant oxygen-poor sea-floor conditions. The bed is renowned for the local abundance within it of beautifully preserved fish, which lived in the much better oxygenated surface waters. Overlying the 'Marl Slate' in the Durham area, was deposited a succession of limestones which, from the common occurrence within them of the magnesium carbonate mineral dolomite, are collectively termed the Magnesian Limestone. A variety of types of limestone, each indicative of rather different depositional conditions, make up this succession. A well-known feature of the Durham Magnesian Limestone is the presence of a very well-preserved fossilized reef composed not of corals as in modern reefs, but mainly of bryozoa and algae, together with a rich marine fauna of bivalves, brachiopods etc. On occasions severe evaporation of the Zechstein sea resulted in the deposition of beds of anhydrite or gypsum, and when evaporation became particularly extreme, beds of rock salt or halite. These rocks, known from their mode of formation as evaporites, are particularly soluble rocks. Dissolution of thick beds of evaporites, possibly during Palaeogene times, resulted in foundering of the overlying limestones producing the strikingly jumbled masses of broken limestones known as 'collapse breccias' which are such a notable feature of parts of the Magnesian Limestone.

Numerous sites in east Durham, and the adjoining Sunderland area, offer some of the world's finest opportunities to study these Permian rocks and to investigate the processes which formed them. They have long been, and continue to be, an important focus of research.

From about 250 million years ago evidence for the county's geological evolution falls largely silent. We know that the county's rocks were again uplifted and tilted gently towards the east, accompanied by some faulting, and that during the Palaeogene Period, about 65 million years ago, narrow dykes of basaltic rock were injected into fractures as distant manifestations of the violent volcanic activity that was then shaping the Hebrides and Northern Ireland. Apart from this we have no tangible evidence of our area's geological history until the deposits left by ice sheets during the glacial period which began here about two million years ago. Much of the form of the present day physical landscape derives from the effects of this prolonged period of ice cover and its subsequent melting.

Centuries of human occupation, and exploitation of the area's natural resources, have further modified the landscape to that which we see today, and which through continuing human influence, continues to evolve.

Selected References

British Geological Survey, 1992, 1996; Duff and Smith, 1992; Burgess and Holliday, 1979; Cleal and Thomas, 1996; Dunham, 1990; Dunham and Wilson, 1985; Forbes et al. 2003; Johnson and Dunham, 1963; Johnson, 1970; 1995; Mills and Holliday, 1998; Mills and Hull, 1976; Smith, 1994; Smith and Francis, 1967; Taylor et al. 1971.

ORDOVICIAN ROCKS

Ordovician rocks formed during the episode of earth history known as the Ordovician Period. This is currently regarded as having extended from around 495 to 443 million years ago.

Ordovician rocks in Great Britain

The succession of Ordovician rocks in Great Britain includes substantial thicknesses of both sedimentary and volcanic rocks. The most complete Ordovician sedimentary succession in Great Britain occurs in central and North Wales. Volcanic rocks comprise a substantial volume of the succession in the latter area. Thick sequences of Ordovician rocks, including both sedimentary and volcanic rocks, are present within the central Lake District and associated inliers. Other extensive outcrops of Ordovician sedimentary rocks occur in the Southern Uplands of Scotland. Smaller outcrops are also present in North West Scotland.

Great Britain's Ordovician rocks were deposited mainly within a deep ocean, known by geologists as the Iapetus Ocean. Thick layers of mud accumulated on the ocean floor, together with substantial amounts of muddy sandstones (commonly known as greywackes), which were deposited by vigorous turbidity currents carrying sediment from the adjoining continental shelves. The Iapetus Ocean lay between two huge continents which, during Ordovician, and succeeding Silurian, times were rapidly converging. Enormous crustal stresses resulting from these continental movements caused widespread subsidence of the ocean basis, substantial volcanic and other magmatic activity, and severe deformation of the rocks being deposited. The continents eventually collided, destroying the Iapetus Ocean, late in Silurian times.

Figure 7. Distribution of Ordovician rocks in Great Britain

Great Britain's Ordovician rocks are important on a regional, national and international level. Their fossil content has contributed a wealth of data which has advanced understanding of evolutionary processes and palaeoecological studies: the rocks have importance worldwide as standards of reference for this episode of geological history.

Figure 8. Distribution of Ordovician rocks in County Durham

Ordovician rocks in County Durham

Outcrops of Ordovician rocks comprise approximately 221 hectares, or 0.1%, of the surface area of County Durham.

Ordovician rocks crop out only in a very restricted area, known as the Teesdale Inlier, beneath Cronkley Fell in Upper Teesdale. Evidence from mapping, and a borehole at Widdybank Farm, suggests that the outcrop may extend to several square kilometres. However, much of this is concealed beneath substantial thicknesses of superficial deposits and exposures are limited to a few small sites alongside the River Tees.

Two main divisions of Ordovician rocks, which can be correlated with rocks in the Lake District, are recognised in the Teesdale Inlier.

Skiddaw Group rocks

The exposures at Pencil Mill, near Cronkley Fell comprise pale grey to greenish grey mudstones, locally with thin gritty laminae. These rocks locally exhibit low grade metamorphism and up to two phases of cleavage: the most intensely cleaved rocks here may be described as phyllites. Despite this alteration some beds have yielded scarce graptolite fossils indicative of the Ordovician *Didymograptus bifidus* Zone. They may therefore be correlated with the Skiddaw Group rocks of the Lake District.

Photo 1. Cronkley Pencil Mill, Teesdale. Old quarry in Ordovician Skiddaw Group slates, formerly worked for making slate pencils.

Although no fossils were found in the poorly cleaved fine-grained greywacke sandstones proved in the borehole at Widdybank Farm, these rocks have also been correlated with the Skiddaw Group rocks of the Lake District.

Metamorphosed slates, proved beneath the Carboniferous rocks in a deep borehole at Emma Pit, Roddymoor Colliery, near Crook, are also correlated with the Skiddaw Group. The metamorphism exhibited by these rocks may be an effect of the Weardale Granite (*see Metamorphic Rocks*).

Borrowdale Volcanic Group rocks

A very small exposure in the banks of the River Tees, a short distance upstream from Pencil Mill, reveals much altered and silicified tuff, believed to correlate with part of the Ordovician Borrowdale Volcanic Group of the Lake District. Several erratic boulders of volcanic rocks, found within the till of Teesdale suggest that the outcrop of Borrowdale Volcanic rocks beneath superficial cover may be more extensive than previously thought and may contain rock types not presently exposed at the surface.

Evidence from the Roddymoor Borehole, a borehole at Allenheads in Northumberland, and exposures on the Pennine escarpment near Cross Fell, suggests that Ordovician rocks are extensively present beneath the Carboniferous rocks across the county.

Influence on the landscape

The comparatively restricted outcrop of Ordovician rocks in Upper Teesdale forms an area of lower ground adjacent to Cronkley and Widdybank fells. However, as these are everywhere concealed by a substantial thickness of glacial deposits except in the very small exposures adjacent to the River Tees near Pencil Mill, these rocks have comparatively little direct influence upon the landscape of the county.

Influence on biodiversity

Because of their extremely limited exposure these rocks have little or no impact upon the biodiversity of County Durham.

Economic use

The soft slates, exposed adjacent to the River Tees, were formerly worked at Pencil Mill for the making of slate pencils. No details are known of the date of working or the amount of material worked, though the quantities produced are likely to have been very small.

Future commercial interest

Future commercial interest is extremely unlikely.

Threats

The few exposures are generally robust and appear to be subject to no particular threats.

Wider significance

The known occurrences of Ordovician rocks within the Teesdale Inlier, and in two boreholes, give the only evidence of the nature of Ordovician rocks in this part of northern England. They therefore contribute much to our understanding of the nature and pattern of Ordovician geology of Great Britain.

Geological SSSIs

The only exposures of Ordovician rocks in the county lie within the Moorhouse - Upper Teesdale National Nature Reserve and SSSI, but they are not specifically designated within the Geological Conservation Review.

Durham County Geological Sites

Skiddaw Group:

Cronkley Pencil Mill,
Upper Teesdale [NY 848 296]

Selected References

Burgess and Holliday, 1979; Dunham, 1990; Johnson, 1961, 1970, 1995.

CARBONIFEROUS ROCKS
– Introduction

Carboniferous rocks formed during the Carboniferous Period, generally regarded as having extended from approximately 354 to 290 million years ago. The term 'Carboniferous', which derives from the abundance of carbon-bearing coal seams within the rocks, was first used in Britain.

Carboniferous rocks in Great Britain

Carboniferous rocks occur extensively within Britain. In much of Britain the base of the Carboniferous System is not exposed, or rests unconformably upon older rocks.

Carboniferous rocks make up one of the most extensive and arguably the most economically important geological units in Britain. These rocks were the source of virtually all of Britain's coal. They attracted the interest of naturalists from the earliest days of scientific enquiry. Many of the basic principles of stratigraphic division and geological structure were established in these rocks. The names used for the major Carboniferous divisions came into use early in the history of geology and this country may in effect be regarded as the 'type district' for these rocks.

At the beginning of the Carboniferous Period Britain was part of a continent known as Laurasia, situated almost astride the equator. During the Carboniferous it drifted north across the Equator from 5 to 10 degrees south to about 5 degrees north. Such movement would have taken the region from the southern hemisphere tropical arid zone, where it was situated during the Devonian Period, through the much wetter Carboniferous equatorial zone into the northern hemisphere tropical arid zone in latest Carboniferous and Permian times.

The succession of Carboniferous rocks in Britain records a gradual change from the early limestone-rich sequences through diverse depositional conditions to the more uniform conditions of late Carboniferous times when widespread fluviatile and deltaic sediments accumulated at or near the prevailing sea level.

Global continental movements initiated towards the end of the Devonian Period resulted in a general north-south extension of the earth's crust beneath the area now occupied by Britain. This produced a series of 'basins' separated by highs or 'blocks' and caused the sea to flood much of the area which had been land at the end of the Devonian. In the early Carboniferous the 'block and basin' topography resulted in the deposition of thick marine shale successions in the rift basins and thin shallow-water limestone sedimentation on the blocks with some areas, such as the Southern Uplands, remaining above the transgressing tropical sea. The blocks were separated from adjacent basins by hinge lines and normal faults along which movement occurred intermittently during sedimentation. Continued earth movements throughout the Carboniferous led to differential subsidence and uplift. Within northern England the buoyancy of the Weardale Granite controlled the evolution of the Alston Block and adjoining Stainmore Trough.

As long ago as the 18th century, three main divisions of Carboniferous rocks, based predominantly on rock type, were recognised: Carboniferous (or Mountain) Limestone, Millstone Grit and Coal Measures. This threefold division has remained more-or-less valid and is reflected in the three age-related terms, **Dinantian**, **Namurian** and **Westphalian** used to describe the rocks in this publication (Table 2).

Carboniferous rocks in County Durham

Outcrops of Carboniferous rocks comprise approximately 185,089 hectares, or almost 83%, of the surface area of County Durham. Table 2 illustrates the terminology employed for this important group of rocks. In consequence of modern research a new classification of British Carboniferous rocks is being developed. Although not yet widely adopted, this new terminology will soon appear on maps and descriptions of the area and is included in Table 2.

The Weardale Granite exerted a very strong influence on the nature of Carboniferous rocks across the area which eventually became North East England, particularly in early Carboniferous times. Granite is less dense than most rocks in the earth's crust. It is therefore rather buoyant, tending to rise relative to the rocks which surround it. Because of this, as the area gradually subsided at the beginning of the Carboniferous Period, the 'block' of Ordovician rocks, together with the Weardale Granite, tended to subside rather less rapidly than the surrounding areas. As a result a much thinner succession of Carboniferous limestones, mudstones and sandstones accumulated on this 'block' than in the adjoining areas. Geologists term this area the 'Alston Block'. A similar 'block' here too partly underpinned by an old granite, comprises the area known as the 'Askrigg Block' of the Yorkshire Pennines. County Durham encompasses much of the Alston Block and the extreme northern most parts of the Askrigg Block. Separating these, in the Stainmore area, is the belt of much more rapid Carboniferous subsidence, and thus of much thicker Carboniferous sediments, known as the Stainmore Trough.

A conspicuous feature of much of the Carboniferous succession of rocks in Northern England is a cyclicity or regular repetition of rock types (*Figure 9*). Periodic change between marine and fluviatile conditions allowed the deposition of well developed and laterally extensive cycles of sedimentation (cyclothems) for which the region is famous. The term Yoredale facies has been used for the repeated upward sequence of limestone, shale, sandstone, seatearth and coal in the Carboniferous of the north of England generally. The cyclicity can be observed at a

Traditional name	Modern Chronostratigraphical divisions		Divisions used on existing 50k geological maps and this document	Divisions likely to be used on maps and descriptions of the area in the future	
Coal Measures	Upper Carboniferous	Westphalian	Coal Measures	Coal Measures	
Millstone Grit		Namurian	Stainmore Group	Stainmore Formation	Yoredale Group
			Great Limestone		
Carboniferous (or Mountain) Limestone	Lower Carboniferous	Dinantian	Alston Group	Alston Formation	
			Melmerby Scar Limestone	Robinson Limestone	Great Scar Limestone Group
			Orton Group	Melmerby Scar Limestone Formation	
			Basement Group		

Table 2. Classification of Carboniferous rocks in County Durham

variety of scales and in varying degrees of complexity. The largest 'cyclothems' occur at the scale of tens to hundreds of metres in thickness. The relative abundance of the different rock types within cycles changes throughout the Carboniferous: Limestone is dominant and coal insignificant in the Lower Carboniferous; sandstone becomes dominant and coal more important in the Upper Carboniferous.

Photo 2. Heights Quarry, Eastgate, Weardale. Great Limestone and overlying shales and sandstones.

It is not appropriate to describe each individual rock unit of the Carboniferous succession. However, it is important to appreciate some of key characteristics of the main rock types present. These are summarised as follows:

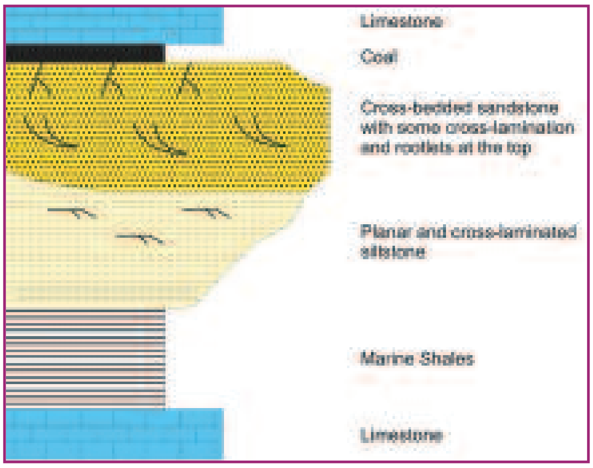


Figure 9. Idealised 'Yoredale' cyclothem

Limestones

Limestones comprise a significant proportion of the lower part of the Carboniferous succession of County Durham, though they become fewer and are separated by increasing thicknesses of other sediments as the sequence is traced upwards. The lowermost limestones are typically pale grey rocks with comparatively few impurities. Higher limestones generally contain significant amounts of clay and bituminous impurities, giving them a rather darker grey colour. Most of the area's limestones contain an abundance of, mainly fragmentary, fossils, though certain limestones, particularly within the Namurian part of the succession, are characterised by rich faunas of corals, sponges etc.

Coals

A feature of the coals of North-East England is their 'rank'. The 'rank' of a coal is its degree of maturity. The effects of temperature and pressure over long periods of geological time tend to expel water and volatile constituents from coal. Thus, a coal which has been subject to elevated temperatures typically exhibits a comparatively low votalile content, high carbon content and high calorific value. In County Durham coal rank increases westwards, with particularly high rank coals present over parts of the concealed Weardale Granite. The little Limestone Coal over much of the North Pennines is of a sufficiently high rank to be described as semi-anthracite. The increase in rank is a result of the heating effects of the concealed Weardale Granite.

The rank of a coal largely determines its use: lower rank coals are well-suited to domestic or power station use, medium rank coals are appropriate for gas and domestic coke production, whilst high rank coals produce good metallurgical coke and anthracites provide smokeless fuels.

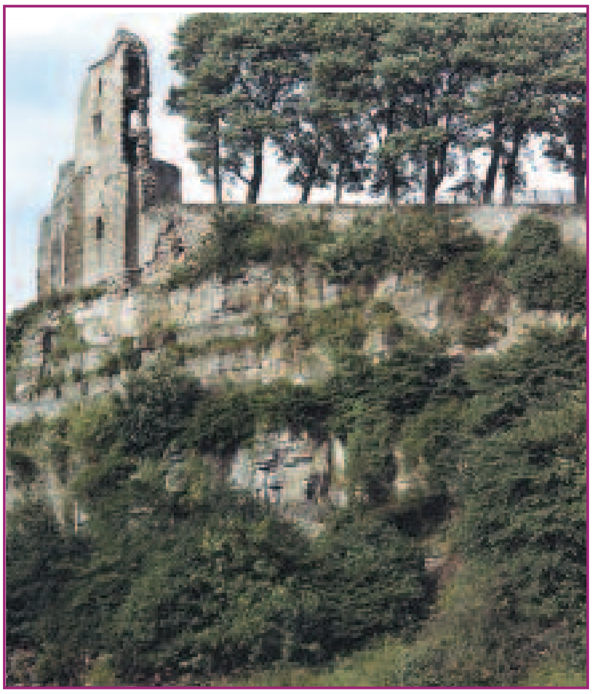


Photo 3. Barnard Castle. The river cliff exposes the Top and Bottom Crag Limestones and intervening beds.

Sandstones

The county's sandstones exhibit a considerable variation, details can be found in the relevant BGS memoirs and other publications. The great majority of the sandstones vary from fine to medium grained rocks, composed mainly of quartz grains, though generally with a small but significant content of feldspar grains, most of which are more or less altered to kaolin. Much coarser, locally pebbly, sandstones are present in places. The sandstones vary from hard, resistant rocks with a well-developed cement, to comparatively weak, in some instances almost friable, rocks where only a weak cement is present. Cross-bedding is extremely common and ripple marks are conspicuous locally. Many sandstones provide clear evidence of erosive bases, clearly betraying their origins as the fillings of channels. Erosion surfaces within individual sandstone units are common. Well-preserved fossils are generally uncommon, though casts of marine brachiopods, bivalves and crinoids locally reveal a marine origin. A few persistent thin beds of sandstone with concentrations of marine shells have been shown to have value as correlative horizons. These include the Knucton and Rookhope Shell Beds. More commonly, certain sandstones exhibit recognisable rootlet traces, or other plant remains, clearly indicative of their origins in a well-vegetated fresh-water or swamp environment. The very large cast of a tree stump and root system, recovered from one of these sandstone beds, and preserved today in Stanhope church yard, is a particularly spectacular example of such a plant fossil. Such sandstones comprise fossil soils or 'seat earths', and may be overlain by a thin coal seam or a very bituminous parting representing the remains of the vegetation. It is common for such sandstones to be significantly richer in silica than many of the other sandstones, and for silica to be the major cementing mineral in the rock. These extremely hard silica-rich rocks are commonly known as 'ganisters'. The high silica content makes some of these beds suitable for the making of silica refractory products for furnace linings.

Cherts

Very fine-grained siliceous rocks called cherts occur locally within the lower part of the Namurian succession in the southern part of the county.

Mudstones and Siltstones

These rock types commonly make up large proportions of the Carboniferous succession, particularly in the Namurian and Westphalian. They are seldom well exposed and, except in one instance, the 'Tynebotton Plate', have not acquired widely used local names.

Ironstones

These occur at several horizons, mostly within the Namurian and Westphalian successions. Most common are concentrations of clay ironstone nodules or thin beds of clay ironstone composed mainly of impure siderite. More rarely, oolitic ironstones occur locally within parts of the Namurian succession.

Shell Beds

Shell Beds are beds in which fossilised shells are especially common: such beds may be sandstones, shales or limestones.

Naming the Rocks

It was the practice of miners and quarrymen to give local names to the rock units, with which they became extremely familiar, particularly the limestones and many of the sandstones. Most of these names were applied at an early date and were adopted by the emerging science of geology as a means of describing the varied stratigraphy of the Carboniferous rocks. These names reflect a variety of intrinsic characteristics. For example:

The Four Fathom and Five Yard limestones reflect typical thicknesses of those units, 24 feet (7.3 m) and 30 feet (9.1 m) respectively.

The Scar Limestone reflects its role in giving rise to landscape features.

The Great Limestone reflects both its thickness and economic importance as a source lime or as a host for mineral deposits.

The Melmerby Scar and Tyne Bottom limestones derived their names from the localities where these units are best developed.

In addition to these stratigraphical names, miners and quarrymen employed local names for rock types. These have not generally been adopted by geological science, though references to them abound on old mine plans and contemporary mine reports.

Hazle (pronounced hezzle) is a sandstone

Sill usually refers to sandstone, or in some instances (e.g. the Coal Sills) a comparatively discreet group of beds consisting predominantly of sandstone.

Flagstones are typically hard sandstones which tend to split readily along, or parallel with, the bedding planes. They may contain thin shale partings which facilitate this splitting.

Photo 4. Namurian shales exposed in North Grain, Rookhopehead, Rookhope. An iron-rich spring flows from a fault cutting the shales.

Grit usually refers to a hard, coarse-grained sandstone, commonly one with a proportion of comparatively softer grains which ensures that the rock maintains a rough surface when exposed to wear in millstones.

Plate was generally used for shales and silty shales.

Selected References

Burgess and Holliday, 1979; Cleal and Thomas, 1996; Dunham, 1990; Dunham and Wilson, 1985; Johnson and Dunham, 1963; Johnson, 1970, 1995; Mills and Holliday, 1998; Mills and Hull, 1976; Taylor et al. 1971.

DINANTIAN ROCKS

Dinantian rocks were formed during the Dinantian Epoch of the Carboniferous Period. This period of earth history is generally believed to have extended from approximately 354 to 327 million years ago. The name Dinantian is taken from the Belgian town of Dinan, where there are good sections in the limestone cliffs of the River Meuse.

Dinantian rocks in Great Britain

The surface outcrop of Dinantian rocks in Britain is shown in Figure 10.

Sedimentary rocks make up the bulk of the Dinantian succession, although volcanic rocks are present locally in the English Midlands, Cumbria and southern and central Scotland. Over much of Britain the pattern of Dinantian outcrops reflects deposition within the pattern of fault-bounded blocks and basins which characterised the Carboniferous period. Within northern Britain these blocks and basins include: the Midland Valley of Scotland Basin, Northumberland Trough, Alston Block, Stainmore Trough, Askrigg Block and the Craven Basin. It is likely that the margins of these block and basins reflect reactivation of existing faults.

The Northumberland Trough, separated from the Midland Valley by the Southern Uplands, was bounded by two active faults which controlled sediment deposition: the North Solway Fault to the north and the Stublick - 90-Fathom Fault to the south. Within the area that is now County Durham, the highs and lows included the Alston Block and the Stainmore Trough, a half-graben bound to the south by the Stockdale Monocline. The Askrigg Block, that extended southwards to the Craven Fault System, lay just to the south of the area under consideration.

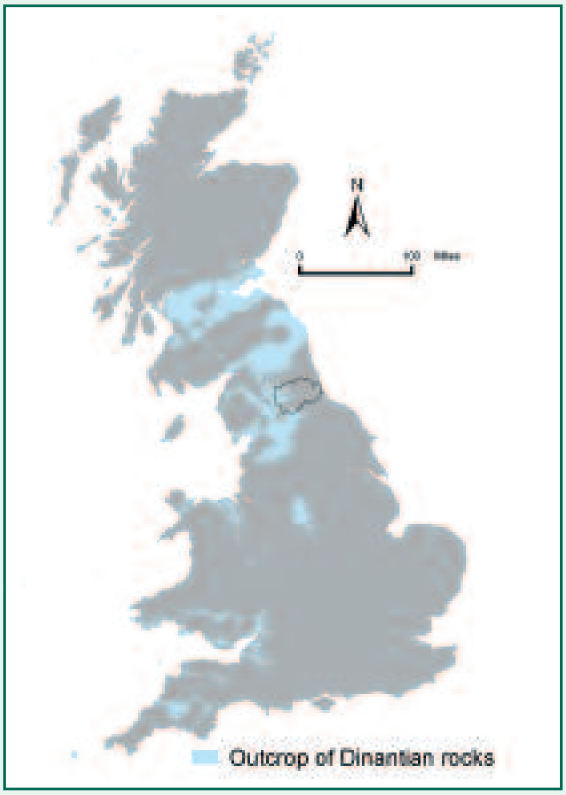


Figure 10. Distribution of Dinantian rocks in Great Britain

Dinantian rocks include a diverse range of sediments which reflect a wide range of depositional environments. Although the succession of Dinantian rocks varies considerably from area to area, across much of northern Britain the rocks record a progressive change from thick marine limestones to the highly characteristic repeated sequences know as Yoredale cyclothems (*Figure 9*). The Carboniferous Dinantian successions of Northern England generally comprise cyclic repetitions of marine limestone alternating with deltaic mudstones and sandstones. Much greater thicknesses of sediments accumulated within the basins than on the intervening blocks, though widespread marine limestones enable correlation between basins and blocks.

Within the Peak District, North and South Wales, the Mendips and Forest of Dean, limestones make up much of the Dinantian sequence. Thin basaltic lava flows and tuffs are locally interbedded with the limestones in the Peak District. In South West England sandstones and mudstones, locally known as the Culm, occupy most of the Dinantian sequence.

The Dinantian rocks of Britain provide evidence of the structural setting during this early part of the Carboniferous period and contain abundant fauna that provides a key for correlation of these strata with those in Europe.

Dinantian rocks in County Durham

Outcrops of Dinantian rocks comprise approximately 25,332 hectares, or 11.3%, of the surface area of County Durham They are mainly in the upper parts of Weardale and Teesdale, with a further outcrop in the extreme south of the county south of Barnard Castle (*Figure 11*). Because of their general easterly regional dip, the oldest beds crop out in the west, and are succeeded eastwards by progressively younger beds.

Within County Durham, Dinantian rocks have been subdivided in various ways. The classification adopted in this publication is based on that used in currently available 1:50 000 scale geological maps:

Basement Group

The Basement Group was the first Carboniferous sediment deposited, following a period of

Figure 11. Distribution of Dinantian rocks in County Durham

Photo 5. Bank of River Tees, Falcon Clints, Teesdale. Exposure of conglomerates belonging to the Orton Group.

erosion in the Devonian and thus rests unconformably upon older rocks. On the Pennine escarpment these beds include conglomerates composed of fragments of the underlying rocks. In County Durham the base of the Carboniferous succession includes similar conglomerates in the Teesdale Inlier. Although these rocks were originally assigned to the Basement Group, more recent work suggests that they may in fact be representatives of the overlying Orton Group. Basement Group rocks appear to have been penetrated in the Roddymoor Borehole at Crook.

Orton Group

In County Durham Orton Group rocks are exposed only in a limited area in Upper Teesdale where up to 40 metres of these rocks include conglomerates, sandstones, shales and impure limestones.

Alston Group

The Alston Group consists of a succession of well-developed typical Yoredale cylothems. Up to 17 named limestones are recognised, though several of these are only developed locally. Individual cyclothems are conventionally named from the limestone at the base of each cyclothem. Whereas most of these cyclothems can be traced across the county and beyond, some are incomplete and cannot be traced across the whole area.

Limestones are the most widespread and consistent in composition and thickness of the rock types within this succession. The thickest Dinantian limestone within County Durham is the Melmerby Scar Limestone. Apart from the Melmerby Scar and Robinson limestones, which are typically pale grey coloured rocks, the limestones of the group are mostly medium to dark grey, in colour. Between the limestones the succession of rock-types, mainly comprising mudstones and sandstones, is much more varied in character and thickness from place to place. Immediately above the limestones, the shales are locally fossiliferous and calcareous and normally pass upwards into dark grey or black rocks, in places with clay-ironstones. Although several of the more prominent sandstones can be traced over large areas, their thickness may vary markedly, and in places the sandstone may be absent. The sandstones are generally fine to medium-grained, composed of subangular quartz grains, commonly with abundant kaolinised feldspar and some white mica. The top of the sandstone

Photo 6. Greengates Quarry, Lunedale. Rocks of the Three Yard Limestone cyclothem exposed in the quarry face.

Photo 7. Lanehead, Weardale. Upland fields on outcrops of Dinantian rocks.

may be a seatearth with abundant rootlet traces and a strong siliceous cement, giving the distinctive rock known as 'ganister'. Coal, if present, is rarely more than a few centimetres thick. Only a few coals in the Alston Group have ever been worked.

In addition to the limestones, all of which were named at an early date by miners and quarrymen, many of the most persistent sandstones were also named. Only one shale unit, the Tynebottom Plate, has acquired a widely used name.

The Alston Group succession within the county may be summarised as follows:

Tuft (Sandstone)
*Iron Post Limestone
Quarry Hazle (Sandstone)
Four Fathom Limestone
Nattrass Gill Hazle (sandstone)
Three Yard Limestone
Six Fathom or High Brig Hazle
Five Yard Limestone
Slaty or Low Brig Hazle
Scar Limestone
*Cockle Shell Limestone
*Single Post Limestone Alternating Beds
*Maize Beck Limestone
Tynebottom Plate (shale)
Tynebottom Limestone
Jew Limestone
Lower Little Limestone
*Grain Beck Limestone
Smiddy = Upper Smiddy Limestone
Rough=Peghorn=Lower Smiddy Limestone
*Birkdale Limestone
Robinson Limestone
Melmerby Scar Limestone (Alston Block)
=Great Scar Limestone (Askrigg Block)

* Indicates those limestones which are typically impersistent and not found across the whole of the county.

= Indicates equivalent names used for this unit in different parts of the area.

Influence on the landscape

Dinantian rocks have a profound influence on the landscape of western County Durham. Weathering of the alternately hard and soft beds within the Yoredale cyclothems has produced a highly distinctive terraced form to many of the hillsides. Limestones and many sandstones are typically resistant to erosion, compared to interbedded shales and softer sandstones. These hard beds thus tend to find expression as steeper slopes, in places marked by small rocky scars: softer beds give rise to low angled slopes or areas of 'slack' ground. In numerous streams and rivers, waterfalls mark the outcrop of many of the harder limestones and sandstones. Fine sections through these rocks, including excellent exposures of complete or near complete cyclothems, may be seen in Bowlees Beck in Teesdale and Middlehope Burn in Weardale. Extensive outcrops of the lowermost limestones, including the Melmerby Scar Limestone, are to be seen around Cow Green in Teesdale. Lines of sinkholes typically mark the position of many of the area's limestone outcrops.

Countless miles of drystone walls, which are such characteristic features of the North Pennines landscape, are built from locally quarried Dinantian rocks, mainly sandstones. These sandstones are also extensively employed as building stones in farms and villages within the Durham Dales. Some thinly bedded sandstones have provided the very distinctive roofing slabs seen on many buildings.

Influence on biodiversity

As with their effect upon the landscape, the Dinantian rocks exert a fundamental influence on the area's biodiversity.

The Melmerby Scar, Robinson and Smiddy limestones in the Cow Green area locally form areas of small bare limestone crags. These provide extremely important habitats for a number of specialised plant communities, including lichens and other lower plants. Outcrops of limestone, where free, or substantially free, of superficial cover, typically support areas of limestone grassland and locally upland ash woods. The comparatively brighter green, more species-rich, vegetation on the limestone, compared to the rather sombre vegetation of the more acidic soils developed on the intervening shales and sandstones, is often a conspicuous landscape feature visible from some distance, and may be a useful clue to identifying limestone outcrops. Carboniferous limestones, where exposed as cliffs tall enough to exclude grazing sheep, are refugia for plants such as alpine cinquefoil and rare grass species. Some cliffs may support nesting sites for birds such as buzzards and ravens. Caves and enlarged joints within natural outcrops and quarries locally serve as important bat roosts.

Outcrops of shales or sandstones, where substantially free of superficial cover, typically support a range of neutral to acidic soils upon which occur neutral to acid grassland and in places oak-birch woodlands.

The diversity of gill woodlands in part reflects the cyclical nature of the underlying Carboniferous strata with a mix of ash woodland on alkaline soils developed on limestone outcrops alternating with oak-birch woodland on the acidic soils formed over outcrops of shales and sandstones.

The pattern of improved pastures and fields, so characteristic of the Pennine dales, owes much to the use of slaked lime produced from locally quarried limestones, including those from the Dinantian succession.

Economic use

Dinantian rocks have been of considerable economic significance within County Durham.

Most of the limestones have been quarried, at least on a small scale, and burnt to provide local supplies of quicklime and slaked lime for use as a soil improver. Countless small quarries and associated limekilns mark the outcrops of these limestones. None of the county's Dinantian limestones is worked today.

The use of Dinantian sandstones as building stones, and their influence on the landscape, has been noted above.

The Dinantian rocks are important host rocks for metalliferous veins and associated replacement deposits.

Future commercial interest

Under present, or currently foreseeable, economic conditions it is unlikely that these rocks will attract significant commercial interest.

Threats

Most of the exposures of, and features associated with, these rocks are robust elements in the landscape. However, suitable vigilance should be exercised to ensure that no operations or activities pose threats to these features.

Numerous abandoned quarries expose important sections through parts of the Dinantian succession. The progressive deterioration of long-abandoned quarry faces, together with risks of quarries being filled and obliterated, pose some long-term threats.

Wider significance

County Durham includes some of the best and most complete examples of 'Yoredale' cyclothems to be seen in Great Britain. These rocks thus provide a wealth of evidence of the geological environments and processes in addition to the important influence of the structural setting on sedimentation during this period of the Carboniferous. They provide an excellent illustration of the effects of blocks and basins and continuing movement of faults that bound them, on sedimentary facies and their thickness.Comparison of this area with adjacent sedimentary basins, such as of the Solway, Midland Valley and Craven basin, allow correlation of rock units to further understanding of the UK's evolution during Carboniferous times.

Geological SSSIs

Dinantian rocks are exposed within a number of areas scheduled as SSSIs. However there are no sites within County Durham specifically designated for Dinantian rocks within the Geological Conservation Review.

Durham County Geological Sites

Black Cleugh, Burnhope	[NY 853 394]
Bow Lees Beck	[NY 907 283]
Green Gates Quarry	[NY 934 236]
Horsley Burn Waterfall, Eastgate	[NY 975 384]
Middlehope Burn	[NY 906 381]
Killhope Burn, Copthill Quarry and Wear River at Butreeford Bridge	[NY 855 406]
Killhope Lead Mining Centre	[NY 823 433]
Scoberry Bridge to Dine Holm Scar	[NY 910 274]
Sedling Burn, Cowshill	[NY 855 405]
Stanhope Burn	[NY 987 398]
Widdybank Fell	[NY 820 290]

Selected References

Burgess and Holliday, 1979; Dunham, 1990; Dunham and Wilson, 1985; Johnson and Dunham, 1963; Johnson, 1958; 1970; 1973; 1995; Mills and Hull, 1976; Scrutton, 1995; Taylor et al. 1971.

NAMURIAN ROCKS

Namurian rocks formed during the subdivision, or epoch, of the Carboniferous Period known as the Namurian, generally regarded as having extended from approximately 327 to 316 million years ago. The name Namurian is derived from the province of Namur in Belgium where these rocks are well developed and have been extensively studied.

Namurian rocks in Great Britain

The distribution of surface outcrops of Namurian rocks in Great Britain is summarised in Figure 12. In addition to these surface outcrops substantial areas of these rocks are known to lie concealed beneath more recent geological deposits.

Within Britain almost all rocks of Namurian age are sedimentary rocks. These comprise a variety of different rock types and distinctive assemblages of rock types to which the term 'facies' is usually applied. These facies reflect the geological environments in which the rocks were deposited. Over substantial areas of the central and southern Pennines and the Peak District, Namurian rocks mainly comprise thick successions of hard, coarse-grained sandstones to which the term 'Millstone Grit' is commonly applied. The Millstone Grit, which derives its name from the suitability of many of its sandstone beds for making grindstones, is one of the most important influences in the landscape of these areas. These sandstones give rise to the bleak moorlands and gritstone 'edges' of the central Pennines around Kinder Scout and the so-called Black Peak, and the gritstone country which lies to the east and west of the Peak District.

In North-East England and Cumbria, Namurian rocks typically comprise thick successions of shales, siltstones and sandstones with some, generally thin, beds of limestone and coals. The broad pattern of 'troughs' and 'blocks' which was established during Dinantian times persisted into the Namurian. The varying thicknesses of the rock sequences deposited clearly reflect the continued influences of these structural units. The alternations of marine limestone with influxes of deltaic muds, silts and sands, established late in Dinantian times continued into the Namurian. The Namurian rocks of Northern England reveal evidence of the transformation from the predominantly marine conditions of the early Carboniferous, or Dinantian, to the almost exclusively freshwater deltaic environments of the late Carboniferous Coal Measures.

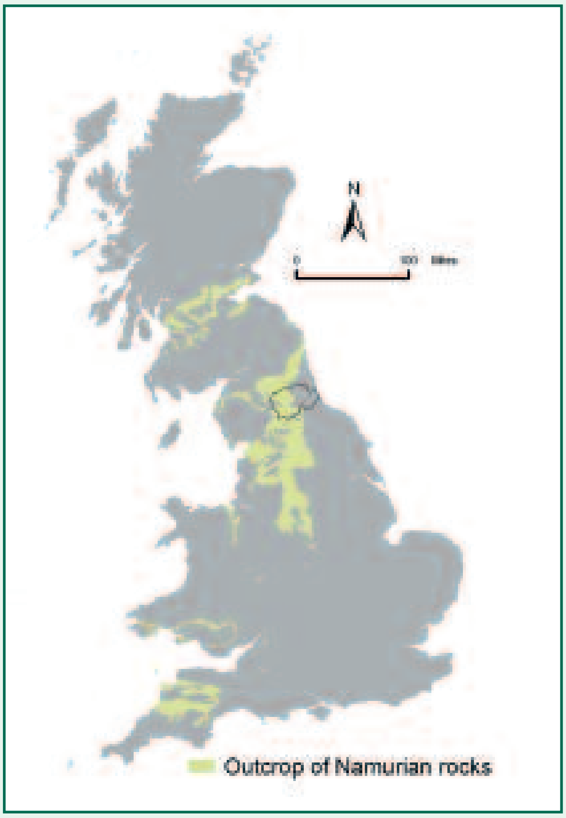


Figure 12. Distribution of Namurian rocks in Great Britain

Namurian rocks in County Durham

Outcrops of Namurian rocks comprise approximately 84,530 hectares, or almost 38% of the surface area of County Durham (*Figure 13*). These rocks have extensive outcrops in the North Pennines where they form much of the higher ground between the Derwent, Wear and Tees valleys and much of the moorland country of the Stainmore area. Namurian rocks dip eastwards where they pass beneath Westphalian rocks. Within County Durham, Namurian rocks have been subdivided in various ways. The classification adopted in this publication is based on that used in the most recently published 1:50 000 scale geological maps.

Stainmore Group

In County Durham the lowest geological formation of Namurian age is the Great Limestone. However, the greater part of the Namurian succession in the county consists of a rhythmic succession dominated by shales and sandstones with a small number of interbedded thin limestones and coals. The limestones in the Namurian succession are typically medium grey, fine-grained, slightly bituminous rocks in which fragments of crinoid and other marine fossils can commonly be seen. Apart from the Great Limestone, the Namurian limestones are typically only a few metres thick at most and commonly exhibit a rather characteristic brown, earthy weathering. The term 'famp' is locally applied to such soft, earthy weathered limestone. Towards

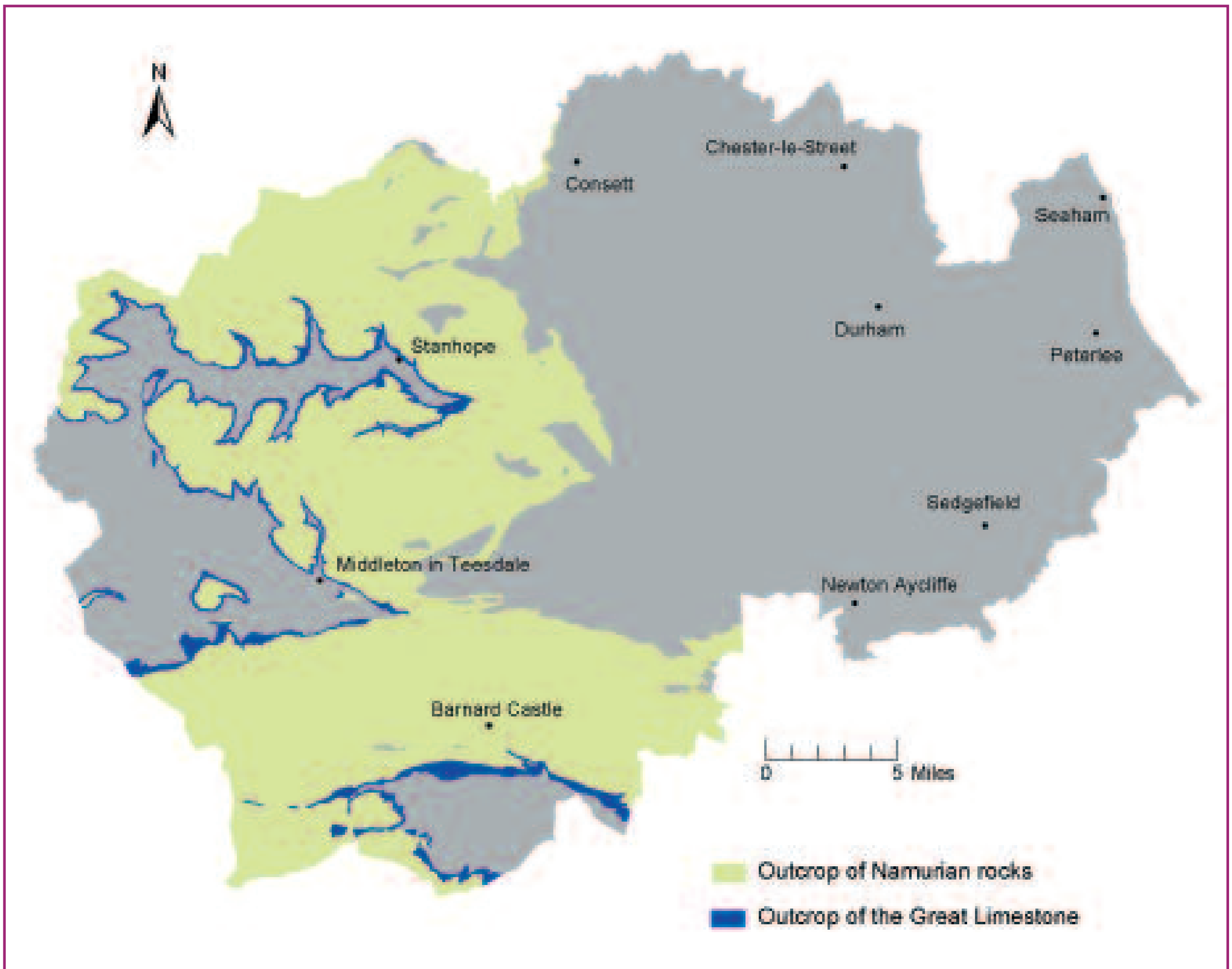


Figure 13. Distribution of Namurian rocks in County Durham

Photo 8. Exposures of 'Second Grit' in banks of River Derwent, Shotley Bridge.

the top of the Namurian succession limestones become fewer and much more impure, locally becoming difficult to distinguish from calcareous sandstones or mudstones.

Namurian sandstones exhibit the characteristics of Carboniferous sandstones described briefly above (*see page 28*). However, many provide clear evidence of erosive bases, betraying their origins as the fillings of channels within the Namurian deltaic environment. More commonly, sandstones exhibit recognisable rootlet traces, clearly indicative of their origins in a well-vegetated fresh-water or swamp environment. The very large cast of a tree stump and root system, recovered from one of these sandstone beds, and preserved today in Stanhope Churchyard, is a particularly spectacular example of a plant fossil from a seatearth sandstone.

Although the term 'grit' has been applied to several of the area's sandstones, some of which have proved suitable for the making of grindstones, it is important to recognise that the sandstones of the North Pennine Namurian succession do not generally exhibit the same lithological characteristics, and were not deposited in precisely the same environment, as the 'Millstone Grit' of the central and southern Pennines. The use of the term 'Millstone Grit' for these sandstones of the North Pennines, although applied in some older geological literature, is today regarded as quite inappropriate for this area.

Most of the coals are very thin, usually a few centimetres thick at most, and impersistent. The thickest and most persistent, which have locally been worked, have acquired local names. The Little Limestone Coal is perhaps the thickest and most widespread of these coals.

Ironstones, typical of the clay ironstones described above, occur at several horizons within the Namurian succession. More unusual ironstones, which seem not yet to have been described in the geological literature, include the distinctive oolitic Knuckton and Rookhope ironstones. The latter is distinguished by the local abundance of chamosite ooliths.

Mudstones and siltstones make up the greater proportion of the local Namurian succession, though they are seldom well exposed and have not acquired local names.

Many of the individual beds within this succession have been named by miners and quarrymen. Although some of these beds may only be present in comparatively small areas, or may occur intermittently across the county, others are persistent and can be recognised across the county and beyond. These named beds are listed below in stratigraphical order. Those known by more than one name, or the names of the correlatives or equivalents elsewhere are indicated:

- Second Grit
- First Grit
- Grindstone Sill
- Botany Limestone
- Upper Felltop = Top Botany Limestone
- Upper Felltop Limestone
- Hipple Sill
- High Grit Sills
- Coalcleugh Marine Beds
- Coalcleugh (=Yoredale or Winston) Coal
- Coalcleugh Beds
- Lower Felltop (=Corbridge) Limestone
- Rookhope Shell Beds
- High & Low Slate sills
- Low Grit Sill
- Hunder Beck Limestone
- Low Stonesdale Limestone (?=Knuckton Shell Beds)
- Knuckton Shell Beds (?= Low Stonesdale Limestone)
- Knucton Ironstone
- Low Slate Sill
- Slate Sills
- Oakwood Limestone
- Crag Limestone = Lower Felltop Limestone
- Firestone Sill
- White Sill
- Pattinson('s) Sill
- Little Limestone
- Little Limestone Coal(s)
- White Hazle
- High Coal Sill = White Hazle
- Coal Sills
- Main Chert
- Great Shale
- Great Limestone (=Main Limestone in the Richmond area)

The Great Limestone is one of the thickest and most extensive limestones within the Carboniferous succession of County Durham (*see Figure 13*). Its name, given to it by early lead miners and quarrymen, reflects both its thickness and economic importance. Over much of the county the Great Limestone averages around 20 metres in thickness, but this increases to around

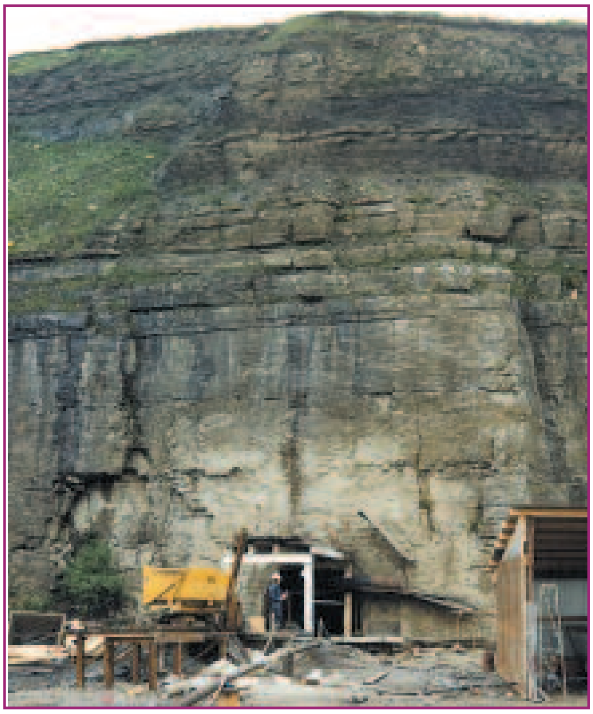


Photo 9. Rogerley Quarry, Frosterley. Great Limestone. The tunnel is one of the experimental drives for the Kielder Water scheme. Photographed 1977.

22 metres in the Stanhope area. Like the majority of the underlying Dinantian limestones, the Great typically comprises a medium-grey, slightly bituminous limestone, in which small fragments of the marine animals crinoids are usually abundant. Complete or fragmentary shells of brachiopods and some bivalves are locally conspicuous and in places both solitary and colonial corals are common. The limestone typically occurs as thick beds, known to local quarrymen and miners as 'posts', which vary from a few centimetres up to almost 2 metres thick. The uppermost 4.5 metres of the formation comprises well-marked 'posts' of limestone separated by beds of dark grey shale up to 0.6 metres thick. The term 'Tumbler Beds' is applied collectively to these upper beds, from their troublesome instability during mining or quarrying.

The following extremely distinctive beds, recognisable over a substantial part of the county, occur within the Great Limestone:

The ***Chaetetes Band*** occurs commonly within 1-2 metres of the base of the Great Limestone. It is a bed, in places up to around 1 metre thick, in which superbly preserved encrusting mats of the fossilized sponge *Chaetetes depressus*, accompanied by colonial corals and a variety of brachiopods, bivalves etc are preserved in growth position. Although very conspicuous in many localities this bed is absent at others.

The ***Brunton Band*** is a bed rich in microscopic algae which occurs locally around 5 metres above the base of the limestone.

The ***Frosterley Band*** or ***Frosterley Marble***, is a bed widely, though not invariably present, around 6 to 7.5 metres below the top of the Great Limestone. It is rarely more than 0.5 metres thick, but locally up to 1 metre thick, and is distinguished by containing variable, but often very abundant, concentrations of the solitary coral *Dibunophyllum bipartitum*, together with other corals and brachiopod remains. Fine natural exposures of the bed are to be seen in Harehope Burn and in Killhope Burn. It is exposed in most of the quarries in the Great Limestone, though is often rather inaccessible in high quarry faces. Particularly good exposures are visible in the abandoned workings of Harehope, Eastgate, Greenfield and Chestergarth quarries in Weardale. The bed, which can locally be extracted in large slabs, takes a high polish. It is not a true marble, but a dark grey to almost black, rather bituminous, fossiliferous limestone.

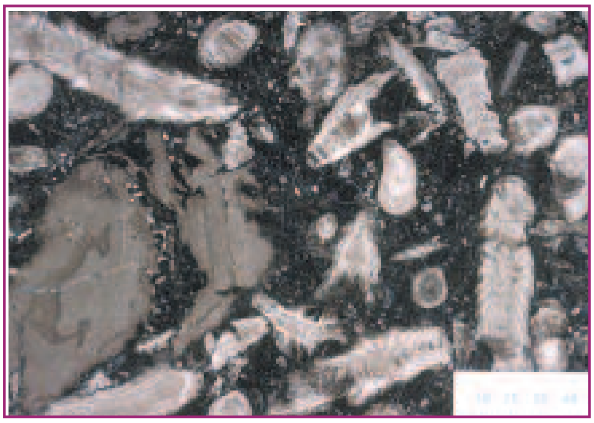


Photo 10. Frosterley Marble. Polished surface.

The ***Knucton*** and ***Rookhope Shell Beds*** are examples of Namurian sandstones which contain concentrations of marine shells and have been shown to have value as correlative horizons.

Influence on the the landscape

Because of their extensive outcrop in the Durham Dales these rocks are of fundamental importance in shaping the landscape and giving it its distinctiveness.

The Great Limestone is well exposed in the sides of many of the valleys and along the Pennine escarpment. It typically forms distinctive pale grey rocky scars or low crags, partially clothed in limestone grassland which commonly contrasts

Photo 11. Coldberry Mine Shop, Hudeshope Valley, Teesdale. Prominent terrace features formed by differential erosion of Namurian rocks.

strikingly with the more acid vegetation on the overlying rocks. In common with other limestones, the Great manifests a number of features characteristic of limestone country, collectively known as 'karst' (*see Karst*). Prominent lines of 'sink' or 'shake' holes clearly mark the top of the Great Limestone along many hillsides (*Photo 57*). As one of the thickest of the area's limestones, the Great has been extensively quarried: abandoned quarries, which expose the limestone and its overlying beds, are conspicuous features in the landscape of Weardale around Stanhope and Frosterley (*Photo 76*). The Great Limestone's role as a host for mineral veins has also impacted significantly on the area's landscape (*see Mineral Veins and Flats*).

Above the Great Limestone the Namurian succession, known as the Stainmore Group, comprises rhythmic alternations of mudstones, siltstones and sandstones with only a few thin limestones and some very thin coals. It is this sequence of rocks which underlies much of the open, and sometimes rather bleak, moorland fell country which typifies much of the Northern Pennines. Much of the outcrop of Namurian rocks is substantially free of any significant cover of superficial deposits. Weathering of the flat-lying, or very gently inclined, mainly shale/sandstone succession has produced extensive areas of rolling moorland with comparatively few natural exposures of rock except in deeply incised streams. Differential weathering of the more resistant sandstones and intervening shales has produced prominent terraced hillsides on which sandstone, and locally thin limestone outcrops, form steep-sided terrace features. In places, where the rock is especially resistant, low grey-weathering sandstone crags occur. Some of the limestones locally give rise to low scarp features. Elsewhere the nature of the underlying rock is betrayed by scattered blocks in the soil or in small pits and quarries opened to provide local sources of building stone for the many miles of drystone walls which are such distinctive elements in the enclosed landscapes of these dales.

The Stainmore Group outcrop in the south of the county around Barnard Castle and Staindrop is much concealed beneath superficial deposits, though a number of prominent sandstones give rise to distinctive ridge-like features.

Influence on biodiversity

In common with their influence on the landscape, the area's Namurian rocks have a significant influence upon the area's biodiversity.

Outcrops of Great Limestone, where free, or substantially free, of superficial deposits, support areas of limestone grassland. The comparatively brighter green, more species-rich, vegetation on the limestone outcrops, compared with the duller vegetation on the more acidic soils on the overlying beds, is often a conspicuous landscape feature visible from some distance, and a useful clue to identifying limestone outcrops. Exposures of weathered limestone, in natural outcrops and abandoned quarries, are important substrates for lichens and other lower plants. Limestone, where exposed in cliffs beyond the reach of grazing sheep, may be refugia for plants such as alpine cinquefoil and rare grasses. Fragments of upland ash woodland occur on some limestone outcrops. Caves and enlarged joints within natural outcrops and quarries locally serve as important bat roosts. Extensive quarrying of the Great Limestone has left a legacy of abandoned quarries which exhibit varying degrees of degradation and regeneration and are commonly hosts to a rich limestone flora.

Although limestones within the Stainmore Group have much smaller outcrops than the Great, and have been much less frequently quarried, small exposures of these rocks locally provide habitats similar to those associated with the Great Limestone.

In common with the outcrops of Dinantian rocks, the diversity of gill woodlands in part reflects the cyclical nature of the underlying Namurian strata with a mix of ash woodland on alkaline soils developed on limestone outcrops alternating with oak-birch woodland on the acidic soils formed over outcrops of shales and sandstones.

However, the bulk of the Stainmore Group comprises shales and sandstones which typically weather to a range of mainly acid soil types. The wide outcrops of these rocks are distinguished by expanses of moorland vegetation, including some fine examples of heather moorland, though management and grazing regimes have resulted in the widespread development of Nardus grassland, known locally from its distinctive pale colour in the winter months, as 'White lands'. Blanket peat of varying thickness, mantles substantial parts of the Stainmore Group outcrop, and there are areas of upland bog and mire.

Economic use

By far the most important economic product of the Namurian succession has been limestone. Whereas many of the limestone units may been employed on a very small scale for the making of quicklime and hydrated lime as a soil improver, by far the most significant has been the Great Limestone. Limestone production assumed large-scale industrial proportions during the late 19th and 20th centuries. Huge quarries in the Great

Limestone of Weardale supplied limestone flux to the iron and steel plants at Consett and elsewhere in the adjoining Durham Coalfield. In addition, limestone from the Great became an important source of crushed rock aggregate, for building and road making. In the second half of the 20th century a new cement works was opened at Eastgate in Weardale, using the Great Limestone as its main raw material. With the recent closure of the works cement making has now ceased. The local demand for limestone flux ended some time ago, and although many of the area's limestone quarries have long been abandoned, the area remains a major source of crushed limestone products from the Great Limestone at Broadwood and Heights quarries in Weardale and from Selset Quarry in Lunedale.

The Frosterley Marble is known to have been worked as an ornamental stone for use in Durham Cathedral and elsewhere as early as the 14th Century (*see Built Environment*). It has been worked intermittently ever since, although the amounts produced over this long period of working are likely to have been very small. For many years little, if any, Frosterley Marble was worked as an ornamental stone except on a very small scale for small ornaments. In recent years Frosterley Marble has been recovered during quarrying of Great Limestone at Broadwood Quarry Frosterley.

The importance of the Great Limestone as a host for metalliferous and related mineral deposits is discussed elsewhere (*see Mineral Veins and Flats*).

Almost all of the sandstones within the Stainmore Group have found use in building drystone walls, farm buildings etc. The names of some of these units gives important clues to their properties and local uses. The Grindstone Sill provided material for grindstones, the Slate Sills commonly offered flaggy sandstones suitable for roofing slabs, the Firestone Sill was locally used as a source of hearth stones. Certain sandstones have, however, found more extensive commercial uses. Siliceous sandstone, or ganister, for making refractory products, was worked from a number of the sandstones. The most extensive of these workings are in the sandstones considered to be part of the Coalcleugh Beds, at Harthope Quarries at Harthope Pass, Weardale.

A variety of other sandstones have been worked for building stone, paving stone and roofing stone. It is generally difficult or impossible to distinguish many of the Namurian sandstones from Dinantian sandstones in buildings.

The Namurian sandstones of County Durham are today an important source of building stone for use both within the county and beyond. Currently active quarries are:

Baxton Law, Hunstanworth	[NY 936 467]
Huland, Bowes	[NZ 015 140]
Dead Friars, Stanhope	[NY 969 454]
Catcastle, Staindrop	[NZ 014 165]
Dunhouse, Staindrop	[NY 114 193]
Harthope Head, Weardale	[NY 864 338]
Shipley Banks, Barnard Castle	[NZ 018 208]
Stainton, Barnard Castle	[NZ 070 188]
Windy Hill, Eggleston	[NZ 022 217]
Woodburn, Satley	[NZ 084 437]
Lingberry, Staindrop	[NZ 085 206]

Several of the Namurian coal seams have been worked, both for local domestic use and for lead smelting. The most extensive workings have been in the Little Limestone Coals. The Yoredale Coal was mined near Winston, east of Barnard Castle and is the only Namurian coal in County Durham to have been worked opencast. Some 111,000 tons of this coal were extracted at the Stubb House site between 1951 and 1953.

Several horizons of thin ironstone beds, or concentrations of nodules, are known within the Namurian rocks of the Stainmore Group. It is likely that some of these may have attracted small scale working in early centuries. Some of the scattered patches of bloomery slags recorded in the North Pennines may mark the sites at which such ores were smelted. There are no records of any substantial working, or exploration, for such sedimentary ironstones.

Future commercial interest

The Great Limestone is likely to remain a source of crushed rock for the foreseeable future, both from existing working sites and conceivably, in the longer term, from new, or currently inactive, sites. Substantial reserves of Frosterley Marble exist within the county. If a means can be devised to extract and dress sufficiently large blocks there may be a small but valuable market for this unusual domestically produced ornamental stone.

Working of sandstone for building stone is also likely to continue both from existing sites and possible from new, or currently inactive, sites.

Threats

Many of the exposures of, and features associated with, these rocks are robust elements in the landscape. However, suitable vigilance

Photo 12. Lime kilns at Skears Quarry, in the Great Limestone, Middleton-in-Teesdale.

should be exercised to ensure that no operations or activities pose threats to these features.

Numerous abandoned quarries expose important sections through parts of the Namurian succession, particularly the very extensive sections of Great Limestone and overlying beds in the huge abandoned quarries around Stanhope and Frosterley. The progressive deterioration of long-abandoned quarry faces, together with risks of quarries being filled and obliterated, poses some long-term threats. The face at Greenfield Quarry, Weardale, noted for its exposure of the Frosterley Band, has been damaged by fossil hunters and research workers. The disused workings of Eastgate Quarry expose several superb sections through important parts of the Namurian succession, most notably the extensive bedding-plane surface exposures of the Frosterley Band. There is a need to address the protection of these features in plans for the after-use of this abandoned quarry. The Frosterley Band exposures, in particular, are worthy of some form of preservation, and would be of great value were they to be made accessible to educational groups or the public.

Wider significance

The Namurian rocks of County Durham provide a wealth of evidence of the geological environments and processes which prevailed during this part of the Carboniferous Period. Comparing and contrasting the detailed nature of individual rock units and the overall succession within the county with adjoining areas is vital to understanding the complex history of Britain's evolution during Carboniferous times.

The lowest formation of the Namurian succession in North-East England, the Great Limestone, marks the last significant episode of limestone formation in the Carboniferous succession. Like all of the marine limestones, it contains abundant evidence of the contemporary marine fauna and flora, and in places, e.g. the Frosterley and Chaetetes bands, exhibits striking examples of complete marine ecosystems fossilised *in situ*.

Above the Great Limestone, mudstones and sandstones become the dominant rock types in the Stainmore Group, as deltaic conditions became progressively more important. Many of the sandstones formed at this time record abundant evidence of their origins as widespread flood deposits or as the fillings of channels within the deltas of which they were part. Namurian sandstones in County Durham contrast both lithologically and in their environment of deposition from the classic 'Millstone Grit' of the central and Southern Pennines.

Selected references

Burgess and Holliday, 1979; Cleal and Thomas, 1996; Dunham, 1990; Dunham and Wilson, 1985; Johnson and Dunham, 1963; Johnson, 1970; 1973; 1995; Mills and Holliday, 1998; Mills and Hull, 1976; Scrutton, 1995; Taylor et al. 1971.

Geological SSSIs

All within GCR Block "Namurian of England and Wales"

SSSI Name	GCR Name	Grid Reference
Botany Hill	Botany Hill	[NY 955 204]
Crag Gill	Crag Gill	[NZ 026 235]
Rogerley Quarry	Rogerley Quarry	[NZ 019 375]
Sleightholme Beck Gorge 'The Troughs'	Sleightholme Beck	[NY 965 116]

Namurian rocks are also exposed within a number of areas scheduled as SSSIs that are not specifically designated for Namurian rocks within the Geological Conservation Review.

Durham County Geological Sites

Chestergarth Quarry, Rookhope	[NY 943 418]
Derwent River Gorge,	[NZ 090 530 – NZ 050 497]
Fine Burn, Bollihope	[NZ 023 351]
Greenfield Quarry, Cowshill	[NY 851 422]
Harehope Quarry, Frosterley	[NY 038 367]
Harthope Head Quarries, St John's Chapel and Langdon Beck	[NY 864 339]
Middlehope Burn	[NY 906 381]
Killhope Lead Mining Centre	[NY 823 433]
Roundhill Quarry, Stanhope	[NZ 011 383]
Stanhope Burn	[NY 987 398]
Sedling Burn, Cowshill	[NY 855 405]
Spurlswood Beck and Quarter Burn, Eggleston	[NZ 022 268]
Stable Edge Quarry, Newbiggin	[NY 919 282]
Teesdale Cave (Moking Hurth Cave)	[NY 868 310]

WESTPHALIAN ROCKS

Westphalian rocks were formed during the Westphalian Epoch of the Carboniferous Period between about 316 and 306 million years ago. The name Westphalian is derived from Westphalia in north Germany.

Westphalian rocks in Great Britain

The rocks are predominantly of sedimentary origin, although volcanic rocks are present in parts of Great Britain. Westphalian rocks are commonly known as the 'Coal Measures' after the coal seams which they contain. Because of their coal, iron ore and clay reserves the Westphalian rocks comprise one of the most economically significant parts of the geological column in Britain. These were the raw materials which were central to the development of Britain as a world power during the late 18th and 19th centuries.

The outcrop of Westphalian rocks in Britain is illustrated in Figure 14. Britain can boast some of the best-exposed sequences of non-marine Upper Carboniferous strata anywhere in Europe.

The Coal Measures of the Midland Valley of Scotland, Northern England, the Midlands, the Pennines, South Wales, the Forest of Dean and the Bristol-Somerset area comprise some of Britain's most important former coalfields. Very substantial areas of Coal Measures rocks, concealed beneath younger strata, have been extensively mined for coal in eastern Yorkshire, the Midlands and Kent. The extensive Coal Measures, proved beneath Jurassic rocks in Oxfordshire have never been exploited.

Coal seams tend to look much like one another. Owing to their economic importance it became important to be able to correlate

Figure 14. Distribution of Westphalian rocks in Great Britain

the coal-bearing rocks between different coalfields. In the absence of many distinguishing features within the coals themselves two types of 'marker horizon' have been used for correlation: marine bands and tonsteins.

Marine bands are thin layers of sediment deposited during discrete marine incursions formed during periods of high global sea level. They are present over very wide areas and contain characteristic fossil assemblages, so that they have become the primary means of correlation within and between coalfields.

Tonsteins are mudstones rich in clay minerals, which are interpreted as having originated as layers of fine airborne volcanic dust. They typically occur as thin beds in coal seams and have proved important for establishing correlations in continental Europe.

In addition the Westphalian is divided into a number zones based on fossils. Five main groups of fossils have been used: goniatites (ammonoids), conodonts, non-marine bivalves, miospores and plants.

The Coal Measures rocks of Great Britain provide important evidence of late Carboniferous environmental conditions and of the fauna and flora at the time. They were deposited as a series of large delta complexes in discrete basins, separated by barriers which formed areas of non-deposition and sometimes erosion. Repeated subsidence of the deltaic coastline, followed by rebuilding of the delta, led to the deposition of a cyclic (cyclothemic) sequence similar to the 'Yoredale' succession (*Figure 9*), distinguished by thicker coals and the general absence of limestone. The typical order in which the main rock types follow one another within the Westphalian is:

Coal

Seatearth

Sandstone

Siltstone

Mudstone (marine band may occur at base)

Coal (of next cycle down)

During Westphalian times equatorial forests of huge primitive trees, ferns and other vegetation flourished on swampy delta slopes and thick deposits of peat derived from the partial decay of this vegetation accumulated from time to time on this surface forming the material that eventually produced coal. The great diversity of form and chemical composition amongst coal 'types' is due, in part, to essential differences in the plant material from which they have evolved, as well as to geological processes, which progressively alter the nature and maturity of coals (*see page 27*).

Photo 13. Reconstruction of Coal Measures swamp.

Figure 15. Distribution of Westphalian rocks in County Durham

Westphalian rocks in County Durham

Outcrops of Westphalian Rocks comprises 75,227 hectares, almost 34% of the surface area of County Durham.

The 'exposed' coalfield occupies a broad outcrop over 32 km wide extending eastwards from Consett, Crook and Woodland towards the coast. East of a line approximately through Sherburn Hill and Shildon and extending to the offshore area, Westphalian rocks dip beneath the

County Index letter applied by the National Coal Board	County Durham	Remarks on local names
A	*[Seam A]*	Hebburn Fell
B	*[Seam B]*	Usworth
C	Ryhope Five-Quarter *[Seam C]*	
D	Ryhope Little *[Seam D]*	
E	High Main	Houghton Three-Quarter, Seaham Five-Quarter
F	Five-Quarter *[Main]*	Dawdon Seven Quarter
G	Main *[Yard]*	North West Durham Brass Thill
H	Maudlin	Bensham
J	(Durham) Low main	Tyne Six-Quarter
K	Brass Thill	Tyne Five-Quarter
L	Hutton	Main of North-West Durham
M	Ruler *[Plessey]*	Ruler of North-West Durham
N	Harvey	Beaumont of West Durham
O	Hodge	Hodge of North-West Durham
P	Tilley	Yard, Constantine of West Durham
Q	Busty	Five-Quarter of West Durham
R	Three-Quarter	Seggar seam of West Durham
S	Brockwell	Main of West Durham
T	Victoria	
U	Marshall Green	
V	Ganister Clay *[Seam V]*	

[Plessey] = Combined Northumberland and Durham name

Table 3. Principal coal seams in County Durham

Permian rocks to form the 'concealed' coalfield. Rocks up to the level of the Ryhope Five-Quarter Coal (Seam B) crop out within the 'exposed' coalfield east of Pittington. The Westphalian rocks of the Durham and adjacent coalfields were laid down in a single depositional basin, which occupied the area between the Southern Uplands High, in Scotland, and the Wales-Brabant High to the south. Rocks of the Lower and Middle Coal Measures crop out within County Durham.

Lower Coal Measures

Traditionally the base of the Coal Measures (Westphalian) in County Durham was taken at the Ganister Clay Coal, considered to be the lowest workable seam. This no longer accords with palaeontological evidence from other coalfields in Britain and north-west Europe, where the base of the Coal Measures is defined by a marine band containing the goniatite *Gastrioceras subcrenatum*. This fossil has yet to be found in North-East England. In 1962 a borehole was drilled for the Geological Survey at High Kays Lea Farm, near Woodland [NZ 0909 2769] with the objective of fixing the position of the *G. subcrenatum* Marine Band and establishing a local geological succession. The borehole indicated that, in the absence of the diagnostic fossil, the most appropriate place to take the base of the Coal Measures in North-East England was at the Quarterburn Marine Band, which is exposed in Quarter Burn [NZ 0170 2676].

Photo 14. Prior's Close Opencast Coal Site, Great Lumley. Fossilised log of Cordiaites in sandstone. Photographed 1997.

The rocks between the Quarterburn Marine Band and the Ganister Clay Coal contain only thin and sporadic coals and are characterised by a high proportion of sandy strata. They were formerly referred to collectively as the Third Grit, of the old 'Durham Millstone Grit Series', thereby emphasising the similarity between this part of the Coal Measures and the highest beds of the underlying Namurian. A marine band at the top of this 'Third Grit', known as the Roddymoor Marine Band, can be seen in Spurlswood Beck [NZ 0172 2660].

The remainder of the sequence, above the Ganister Clay coal, contains widely persistent coals although seams thicker than 0.9m, and most of the productive seams, are largely confined to the beds above the Brockwell Coal. Below the Brockwell seam sandstones tend to be coarse and some are siliceous enough to be termed ganister.

Middle Coal Measures

As with the Lower Coal Measures, sandstone forms more than half of the Middle Coal Measures The Middle Coal Measures contain the majority of the workable coals, together with most of the marine strata and the best-known flora and fauna. The base is taken at the base of the Harvey (Vanderbeckeii) Marine Band. Fossils are recorded from several levels in the sequence. An important mussel band, sometimes with fish debris at the base, occurs closely above the Harvey Marine Band and is one of the most persistent marker bands of the Durham Coal Measures. A maximum of about 210 metres of Middle Coal Measures above the High Main Coal, probably as high as the Hebburn Fell Coal (Seam

Photo 15. Cobey's Carr Quarry, near Willington. Typical Coal Measures shales and sandstones.

A), are present beneath Permian rocks in the 'concealed' coalfield. In the Durham coalfield as a whole these beds contain five marine bands, named in upward succession the High Main, Little, Kirkby's, Hylton and Ryhope. The Middle Coal Measures above the High Main include massive sandstones, such as the High Main Post, overlying the High Main Coal, and the Seventy Fathom Post, which was worked for grindstones

Coal Seams

Traditionally, each colliery applied its own set of seam names. This led to much confusion and to a proliferation of local names. Thus, not only were individual seams given numerous local names, but where the same name was used in different collieries it was commonly applied to different coals. Later, standard sets of names were established separately in County Durham and Northumberland, but only in a few instances (notably in the lower measures) were similar names used for the same coals. This led to further confusion, a situation made worse by the frequent miscorrelation of seams within and between the two counties. In 1957 The National Coal Board, Durham Division, devised a system to indicate the correlation of coal seams "… in order to end the confusion which has resulted from the use of names alone". The workable coals present in the Coal Measures of County Durham were all referred to twenty-one principal horizons and each horizon was allocated a standard county name and also a correlation index letter. The purpose of the index letter system was to ensure accurate correlation even when seams were split or linked with another seam. The system was later extended to include the coals of Northumberland and for the most part the Durham names were retained.

In addition to the principal seams listed in Table 3, there are other, smaller seams, both separate horizons and leaves of larger seams, which have not been listed. Some of these may have been of sufficient thickness and quality to have been mined over limited areas. Most of the productive seams were concentrated in the middle of these strata from the Brockwell to the High Main. With the advent of opencast coal extraction practically every coal greater than a few centimetres in thickness has been excavated at some point.

The coal names themselves provide a fascinating avenue for study and interpretation:

One of the most famous of the Durham seams is the Hutton, its name being almost a household word during the first half of the 20th century. At the end of 1959, the seam was being worked at thirty-nine collieries within Durham. The lowest important member of the group of seams lying above the Harvey Marine Band, the seam is found at an average distance of about 30 metres above the marine band. Although the origin of the name Hutton is obscure, its use can be traced back for over 200 years. The earliest reference obtained is in connection with the "Grand Allies"

Photo 16. Panoramic view from Mountsett, near Stanley. Landscape typical of the western part of the Coalfield.

who, in 1727, worked royalties in the Pontop area and formulated a scheme for the regulation of the sale of coal, in which the output of a Hutton Pit is mentioned.

The coals of Durham have been mined extensively from both exposed and concealed portions of the coalfield. They cover a range of rank from coking coals in the west to lower rank, high-volatile bituminous coals in the east.

Even though Westphalian rocks underlie such a high percentage of the county, it is not easy to examine them in Durham. They are extensively concealed by glacial drift and exposure is confined the banks of the major rivers and their tributaries, abandoned quarries and clay pits, and to isolated outcrops, commonly of sandstone, on steeper or higher ground. Natural sites are generally disappointing and excavations are few and ephemeral. Quarries are most commonly in sandstone. Much of the stratigraphical information on the Coal Measures of Durham has come from borehole, shafts and underground workings. However, the advent of large-scale opencast coal extraction in the second half of the 20th century provided the opportunity for detailed examination of the rocks in active opencast sites. Consequently the sections used for most of the recent research and advances in understanding of the Westphalian rocks in Durham have either been quarried away or buried on completion of coal extraction.

Influence on the landscape

In the western parts of the coalfield the landscape of the Durham Coalfield Pennine Fringe is made up of broad ridges and shallow valley heads of the coalfield valleys. The soft and thinly bedded sandstones, shales and coals of the Coal Measures are here generally free of drift or locally masked by boulder clays giving rise to gently rounded convex slopes. Occasional thicker sandstone beds are marked by steeper bluffs. The Tyne and Wear Lowlands within County Durham are everywhere underlain by Coal Measures rocks, though an extensive mantle of superficial deposits greatly limits their direct influence upon the landscape. Exposures of Coal Measures rocks are here mainly restricted to incised valley sides, though sandstone outcrops are traceable as ridges where superficial cover is thin valleys.

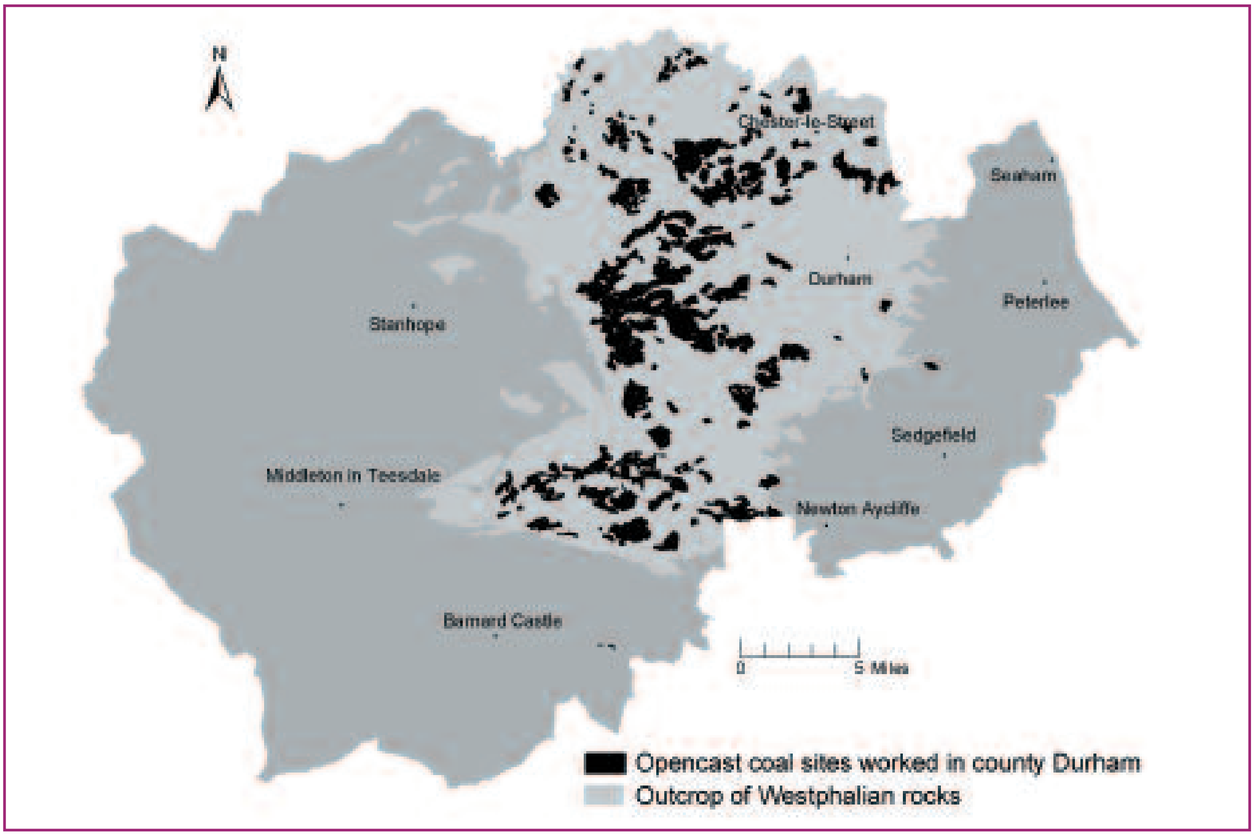


Figure 16. Location of Opencast Coal Sites in County Durham

Centuries of coal working have greatly modified the natural landscape. The general settlement pattern in the coalfield consists of small, scattered communities that developed around individual collieries Substantial areas have been greatly altered by opencast coal extraction and subsequent infilling since the Second World War II. Over the years, areas affected by opencast coalmining have spread to cover a significant proportion of the exposed coalfield with over

Photo 17. Brusselton Hill, near Shildon. Landscape of the eastern part of the Coalfield with the Magnesian Limestone escarpment in the distance.

120km^2 having been worked or had approval for working (*see Figure 16*). The pattern of open-casting in Durham, with large numbers of relatively small sites, and re-working of areas has led to a widespread loss of traditional landscape features and associated wildlife. This has had a significant impact on the area, with the loss of subtle landscapes developed over centuries, which not even sympathetic restoration schemes can recreate adequately.

The coalfield is now generally seen as a predominantly rural landscape with a rich industrial heritage, which is preserved and celebrated in The North of England Open Air Museum at Beamish and the Timothy Hackworth Victorian and Railway Museum at Shildon. The Durham Coast, at one time one of the most despoiled in Europe, has been the subject of a major reclamation initiative in the Turning the Tide Project and much of it is now designated as Heritage Coast.

Influence on biodiversity

Over moorland parts of the county the Westphalian rocks support a vegetation pattern extremely similar to that found on the Namurian rocks above the Great Limestone. On poorly drained ridges and plateaux, peaty gleys and deeper peats have formed, supporting heathland vegetation of heather, bilberry and acid grassland and locally oak-birch woodland. Valley sides incised through the superficial deposits into the Coal Measures rocks are typically wooded. An extensive mantle of Quaternary deposits, mainly boulder clay or till, conceals substantial parts of the Coal Measures outcrop. In such areas the biodiversity typically reflects the nature of these superficial deposits rather than the underlying Coal Measures rocks. Although the extensive opencasting in the county has lead to a loss of natural wildlife, modern restoration schemes have increasingly taken into account wildlife considerations and several successful habitat creation schemes have been undertaken.

Photo 18. Horden Colliery, photographed in 1973.

Economic use

Coal

The Northumberland and Durham coalfield was the first British coalfield to be developed commercially. The earliest mention of coal-mining by the monks of Durham is in 1188, but workings only seem to have become important during the 14th century, when a considerable revenue began to be derived. In 1820 a new era opened when Hetton Colliery shaft was sunk through the Magnesian Limestone to the Hutton Seam in the concealed part of the coalfield. In its peak years of production almost the entire output of coal from the Durham coalfield was obtained from underground mines. In 1913 over 41 million tons of coal were raised and 132,000 men employed in the collieries of the county. Exhaustion of reserves and economic factors led progressively to the closure of the large deep coal mines in the 1980's. During the final years of deep mining coal extraction became concentrated in a handful of amalgamated coastal collieries in which workings extended up to 5 km offshore. The closure of Park Drift Mine, near Willington in 1999 brought underground coal mining in Durham to a close. Opencast extraction, which started during the Second World War, reached its peak in the early 1990's when over 14,000 tons were extracted annually.

Fireclay

Fireclays are non-marine sedimentary mudstones and occur as seatearths, the fossil soils on which coal-forming vegetation once grew, which underlie almost all coal seams. The term 'fireclay' is used to describe seatearths which are of economic interest and they are generally named after the overlying coal. The Durham coalfield has historically been an important source of fireclay. Up to the Second World War, before the advent of opencast coal mining, all fireclay was extracted by underground mining. The last two fireclay mines near Bishop Auckland closed in 1975. Originally fireclays were valued as refractory raw materials, because of their relatively high alumina and low alkali contents. Demand today is comparitively low for refractory purposes, but some fireclays with low iron contents compared with other brickmaking clays are now valued for the production of buff-coloured facing bricks and pavers. They are often blended with red-firing brick clays to give a range of fired colours.

Fireclay production is today dependent on the level of opencast coal activity. Several fireclays within the Lower Coal Measures are of economic interest for brick manufacture, most notably those associated with the Tilley and Busty seams and, to a lesser extent, the Victoria and Brockwell.

Brick-making

Small brickworks mainly producing 'common' bricks' from locally won raw materials, including clay, mudstone (shale) and fireclay were formerly a common feature in many industrial areas of Britain.

The Union brickworks near Birtley lies in Gateshead Borough, although the clay working which supplies it is in County Durham. Mudstones which meet the requirements of the brick industry today are very limited, but bricks are produced at two locations in County Durham based primarily on Coal Measure mudstone won from on-site pits. Both plants are in the Bishop Auckland area and also consume varying tonnages of fireclay brought in from opencast sites. The plant at Todhills produces a range of red and buff facing bricks using the soft-mud process. Buff bricks are based on a blend of fireclays, the red bricks are made primarily from mudstone. The Eldon plant produces a range of red and buff facing bricks using the extrusion process and also makes class 'B' engineering bricks.

Sandstone

Coal Measures sandstones have been widely used as building stones. The finest examples of

Photo 19. Hown's Quarry, Consett. Underground quarries in the sandstone between the Marshall Green and Victoria coals.

their use within the county are in Durham Cathedral and Castle, though they were also widely used across the coalfield. Sandstones from the Coal Measures have been much used in dry stone walls in the western parts of the coalfield. Coal Measure sandstone is still quarried at Quickburn, near Satley [NZ 080 428].

Future commercial interest

Future commercial interest in the coalfield is likely to be confined to sites suitable for opencast extraction. The economics of coal extraction have changed with time, allowing coals with higher overburden ratios to be extracted. Some sites, or parts of sites, have been worked on more than one occasion and may be worked for deeper coal in the future. However sites worked within the last 25 years are likely to have exhausted the economically recoverable coal resources. County Durham still contains reserves of coal suitable for opencast extraction and although extraction today is on a much smaller scale than in the past it is likely that as one site closes operators will wish to open another. Only one opencast coal site was in active production in April 2004, at Southfield, south-east of West Auckland. Continued interest in the working of fireclay, brickclays and sandstone may be expected.

Wider significance

During their long history of exploitation the Coal Measures rocks of County Durham have contributed greatly to the understanding of Westphalian rocks both in Great Britain and beyond. The exposure in the Quarter Burn, near Woodland, is the type locality of the Quarterburn Marine Band, the bed taken in North-East England to mark the base of the Coal Measures. However, exposures of Coal Measures rocks available within the county today pale into insignificance by comparison with the extensive coastal sections of these rocks in Northumberland.

Environmental issues

Centuries of underground coal mining have left an indelible mark on the county both above and below ground. The widespread dereliction left by the industry affected the quality of the landscape, the health of the environment, and the image of the county to those outside of it. A major reclamation programme lead by Durham County Council has been operating since the early 1960's to considerable effect, and has reclaimed over 44 square miles (144 km^2 of derelict land. Over much of the coalfield it is now hard to find evidence of coalmining. Those features which survive – old waggonways, viaducts and coke ovens – are now valued as part of the area's mining heritage. The nature of modern opencast working involving the movement of large amounts of material makes it a particularly suitable method of addressing contaminated and/or derelict land. Since 1997 several opencast schemes have successfully addressed areas of contamination.

During the course of underground mining vast quantities of waste rock were brought to the surface. Accumulations of such spoil are associated with most mines, large and small. Colliery spoil typically comprised waste shale, often with high concentrations of pyrite, and in places a significant content of inferior or undersized coal. Oxidation of these materials can result in spontaneous combustion or, more commonly, the development of highly acidic groundwaters. Leachates from such spoil heaps may present significant threats to land and the ecosystems of water courses. Contaminated water leaching from colliery spoil in the headwaters of the Stanley Burn, near Annfield Plain, have been successfully remediated by a purpose-built wetland system. Whereas the largest and most disfiguring spoil heaps have today been removed by a variety of reclamation and landscaping schemes, these mostly involved the redistribution of the waste over the surrounding ground and its covering with topsoil. However, unless appropriate remedial measures were incorporated into the reclamation method, the potential for significant environmental problems may remain. Even after a very few years such reclaimed ground may be very difficult to identify. It is therefore important to ensure that the nature and extent of such accumulations of spoil are adequately mapped and recorded.

The environmental aspects of dumping of colliery waste on the Durham coast are discussed briefly below (*see Spoil Heaps*)

Significant areas of the exposed coalfield are affected to some extent by surface collapse or subsidence, one of the most obvious manifestations of underground coal mining. In addition to the possibilities of damage to buildings and structures, subsidence may impede effective drainage through surface water courses and may result in temporary or even permanent flooding of land. Although reactivated movement or subsidence associated with known

Photo 20. Iron-rich minewater discharge. Stony Heap, near Lanchester.

faults in exposed Coal Measures rocks is well known form other parts of Great Britain, for example in Staffordshire and South Wales, this phenomenon is not known to have been recognised to date in the exposed part of the Durham Coalfield. Ground stability related to possible reactivation of faults and fissures in the Magnesian Limestone are discussed briefly below (*see Magnesian Limestone*).

Although pumping of mine water continues at several places in the county, ground water levels in some areas of former mining are known to be rising. Such groundwater may be highly acidic and heavily charged with a variety of chemical elements, notably iron, manganese and aluminium. In uncontrolled situations this water may discharge naturally to the surface via former mine openings or even through geologically controlled pathways such as faults, fissures, or permeable rock formations. Serious contamination of land and water courses, accompanied by attendant effects on biodiversity, may result. A number of such discharges may be seen in County Durham: a particularly striking example is that at Stony Heap, near Lanchester where thick deposits of ochre are being deposited on the banks and bed of the stream. Controlled pumping and conditioning of the discharged water is being undertaken elsewhere in the county, for example at Kimblesworth and at Edmondsley.

Most coals and coal-bearing rocks contain significant quantities of methane, commonly known as ‘firedamp’. Efficient ventilation was imperative in working collieries to avoid explosions. Methane may continue to be released long after workings are abandoned. In old and unventilated workings large volumes of de-oxygenated air, otherwise known as ‘black damp’ or ‘stythe’ may form. These gases may find their way to the surface, often driven by rising water levels. Discharge may not be restricted to former mine openings. Faults, fissures and permeable rock units, especially where a protective surface cover of superficial deposits is thin or absent, may form very effective pathways conveying gases to the surface, in some cases many tens or even hundreds of metres from the workings in which they were formed. In confined or poorly ventilated situations, these gases may present serious risks to health and safety. Instances of surface discharges of mine gas are understood to have affected several parts of the county.

Subsidence, mine water contamination and mine gas problems all impact upon biodiversity, human safety, and economic activity. Their successful management and remediation depends upon the application of a detailed knowledge and understanding of the key factors of the county’s geodiversity.

Photo 21. Gas vent to allow drainage of mine gases from old workings.

Geological SSSIs

There are no sites in County Durham specifically designated for Westphalian rocks within the Geological Conservation Review.

Durham County Geological Sites

Binchester Crags	[NZ 210 330]
Causey Burn	[NZ 199 556]
Craghead Crags, Lintzford	[NZ 1409 5732]
Gaunless River	[NZ 2173 3014]
Middridge railway cutting	[NZ 250 251]
Underground tunnels at Easington Colliery	[NZ 437 443]
Spurlswood Beck and Quarter Burn, Eggleston	[NZ 022 268]
Wear River Gorge at Durham City	[NZ 273 417]

Selected References

Atkinson, 1968; Burgess and Holliday, 1979; Cleal and Thomas, 1996; Dunham, 1990; Galloway, 1882; Jevons, 1915;Johnson, 1970; 1973; 1995; Magraw, 1975; Mills and Holliday, 1998; Mills and Hull, 1976; Scrutton, 1995; Smith, 1994; Smith and Francis, 1967; Taylor et al, 1971.

PERMIAN ROCKS
- Introduction

This section provides a general introduction to Permian rocks and introduces the principal divisions in use today. Details of the rocks in these divisions are described in subsequent sections.

They are rocks laid down during the Permian Period about 290 to 248 million years ago. The term Permian was first used in 1844 for strata near the city of Perm in the Ural mountains, Russia.

Permian rocks in Great Britain

Permian rocks in Britain include both continental sediments or 'red beds' deposited mainly under desert conditions and marine sediments. The marine Permian, in particular, comprises a series of rocks which are relatively complex and can be extremely difficult for the non-specialist to identify and differentiate.

Permian rocks of desert origin occur in isolated areas throughout the length of Britain from the Hebrides to classic coastal sections in Devon. Late Permian marine and associated strata are restricted to northern England with widely scattered, but mainly small, occurrences in northwest England and extensive almost continuous outcrop from Tynemouth in North-East England southwards to the outskirts of Nottingham. The Youngest late Permian marine strata are present *in situ* only in the southern North Sea. They are known almost entirely from borehole evidence.

During the early Permian, northern Europe was one of the world's great deserts. Widespread barren uplands created during the preceding Variscan earth movements were gradually worn down by Permian desert erosion and up to 500 metres of Carboniferous rocks were eroded (*The Geological Evolution of County Durham*). The product of this prolonged phase of erosion was a mature, gently rolling plain, probably with, in present-day North-East England, a gentle eastward slope into the subsiding North Sea Basin. This plain became the Carboniferous-Permian unconformity, a surface of generally low relief on which the Permian Yellow Sands Formation was deposited. In Northern England in the late Permian, continental extension opened a seaway which flooded low-lying ground and formed inland drainage basins, the so-called

Figure 17. Distribution of Permian rocks in Great Britain

Bakevillia and Zechstein seas, approximately in the areas now occupied by the Irish and North seas. Situated in tropical latitudes about 10 degrees north of the equator at the start of the Permian, the area that is today Northern England had moved to about 30 degrees north by the end of the Period. During the early Permian northern Europe was one of the world's great deserts. Widespread barren uplands created during the preceding Variscan earth movements were gradually worn down by Permian desert erosion and up to 500 metres of Carboniferous rocks were eroded. The product of this prolonged phase of erosion was a mature, gently rolling plain, probably with, in present-day North-East England, a gentle eastward slope into the subsiding North Sea Basin.

Permian rocks in County Durham

Outcrops of Permian rocks comprise approximately 35,273 hectares, or 15.8%, of the surface area of County Durham

The primary divisions of the Durham Permian were established in the early work of the eminent geologist Sedgwick published in 1829. The classification used by geologists today has evolved gradually as successive discoveries have enabled later workers to refine to this pioneer work. Most notably, a new formalised system of names based on geographic locations was introduced in the 1980's. However, some of the names used by Sedgwick have become embedded in both the geological literature and the general understanding of people in the county. In particular, no discussion of the Permian rocks of Durham would be complete without reference to the Magnesian Limestone, a name that is no longer in formal geological usage. It is so widely employed in descriptions of the county that the term is retained in this report. A comparison between the traditional and more recent names is given in Table 4.

Rotliegend Group

The oldest Permian rocks within County Durham are sands and breccias, which were formed under desert conditions and deposited only in restricted areas.

Formal name (modified from Smith, 1989)		Traditional name			English Zechstein cycle
Zechstein Group	Rotten Marl Formation	Rotten Marl			
	Boulby Halite Formation	Middle Halite			EZ3
	Billingham Anhydrite Formation	Billingham Main Anhydrite			
	Seaham Formation	Magnesian Limestone	Upper	Seaham Formation	
	Seaham Residue and Fordon Evaporite Formation			Seaham Residue	EZ2
	Roker Dolomite Formation			(Hartlepool and Roker Dolomite)	
	Concretionary Limestone Formation			(Concretionary Limestone)	
	Ford Formation		Middle		EZ1
	Raisby Formation		Lower		
	Marl Slate Formation	Marl Slate			
Rotliegend Group	Yellow Sands Formation	Yellow Sands (Basal Permian Sands and breccia)			

Not exposed onshore in County Durham

Units described in this report

Table 4. Classification of Permian rocks in County Durham

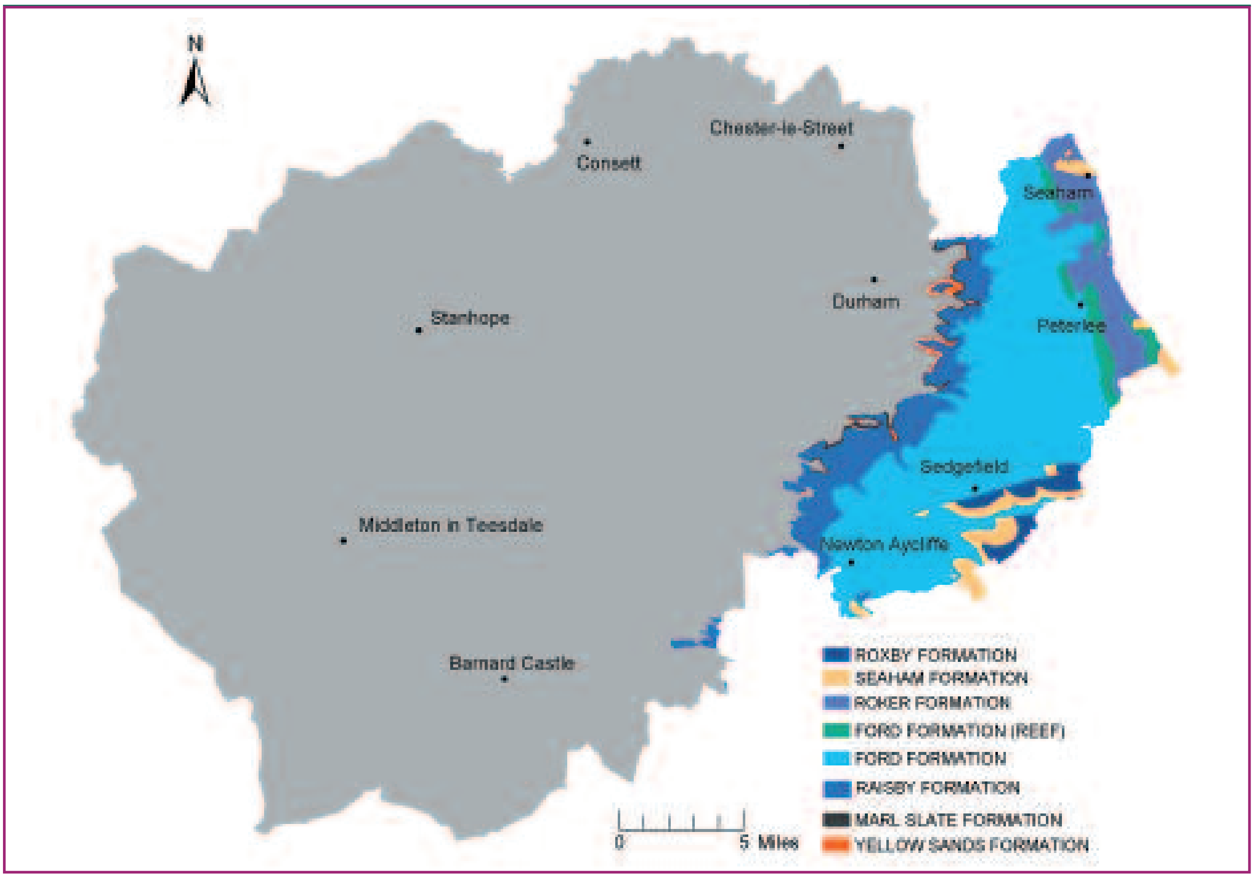


Figure 18. Distribution of Permian rocks in County Durham

Zechstein Group

The Zechstein Group or late Permian marine succession in Durham formed near the western margin of the Zechstein Sea. The Group is made up of four main depositional cycles traditionally interpreted as the result of flooding by, and subsequent evaporation of, the Zechstein Sea. Where complete these cycles range from carbonate rocks at the base through sulphates to chloride-bearing 'evaporites' at the top. The inferred shoreline was only slightly to the west of the present Permian outcrop and a barrier reef formed near the edge of the sea. This was broadly similar to the Great Barrier Reef of Australia today, though composed principally of bryozoa and other marine organisms, but with few corals, The reef was essentially a large, flat-topped ridge sub-parallel to the coast with the top at, or just below, sea level. It formed a barrier between the open sea and an inland shallow water lagoon in which carbonate deposition was taking place. The sea periodically became sufficiently concentrated to deposit beds of gypsum, anhydrite, halite and potash alongside and on top of the reef. However, as these evaporites are mainly soluble salts, subsequently they have been dissolved away by natural processes and are not present at outcrop in County Durham. They are only locally represented by collapsed and broken limestone beds, with faint residues in places. All younger rocks of the late Permian sequence in coastal and adjoining inshore parts of the district have foundered as a result of this dissolution of underlying and interbedded evaporites. In County Durham the Rotten Marl is seen only in collapse breccias.

Some of the lowest rocks (cycle EZ1) in Durham differ considerably from their counterparts in Yorkshire, but remaining parts of the sequence are broadly comparable.

Photo 22. Crime Rigg Quarry, Sherburn Hill. Thick Yellow Sands beneath Raisby Formation and Marl Slate.

Wider significance

The Permian rocks of Durham are commonly extremely well exposed and have attracted so much detailed study that Durham can claim justifiably to be the type area of the marine Permian in Britain. Some of the coastal sites in Durham are without parallel in Britain and most of western Europe and are unrivalled for research and teaching purposes. They are mainly in limestones and dolomites in the upper part of the Permian marine sequence and, in addition to exposing a continuum of rock types characteristic of the varied Permian marine environments, also furnish magnificent examples of the disruptive effects of evaporite dissolution.

At depth onshore, because of their highly porous nature, the Yellow Sands are major sources of groundwater and, offshore in the North Sea they are important reservoirs for oil and gas. Interest in these rocks was renewed as a result of exploration for oil beneath the North Sea in the late 20th century, as detailed examination of the exposures onshore enabled geologists to better understand Permian rocks concealed beneath the sea-bed.

The Marl Slate of County Durham area is internationally renowned for well-preserved vertebrate fossils, most notably several species of fish, though there are also important sites for early reptile fossils.

Selected References

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1994, 1995; Smith and Francis, 1967; Smith et al. 1974; Smith et al. 1986.

YELLOW SANDS FORMATION

The Yellow Sands Formation (Yellow Sands or Basal Permian Sands and Basal Breccia) is part of the Permian succession. There is no independent evidence for the age of the Yellow Sands Formation, but it is generally considered to be late Early Permian (approximately 270 million years old).

The Yellow Sands Formation in Great Britain

The Yellow Sands Formation covers about two-thirds of the Carboniferous-Permian unconformity in Northern England. It is a sequence of rocks restricted onshore to Northern England in Durham, Tyne and Wear, Cleveland and northernmost North Yorkshire, South and West Yorkshire. It also extends beneath the North Sea.

The Yellow Sands indicate that in early Permian times deposits were laid down in continental conditions in a hot, arid desert environment. Deserts today provide excellent analogues for understanding the ancient desert sedimentary systems of the British Permian. Examination of the ancient sand dunes enables factors such as the direction of sand transportation by winds of the time to be understood.

The Yellow Sands Formation in County Durham

The Yellow Sands Formation consists mainly of weakly cemented, yellow fine- to medium-grained, well-sorted sands or sandstone of wind blown origin. Beautifully rounded and frosted “millet seed” grains are abundant in most samples of the Yellow Sands. At outcrop the sands are typically bright yellow, due to a thin coating of limonite on many of the grains, although patches of white or light grey sand can also be seen in large sections. At depth, below the zone of oxidation, the sands are blue-grey and pyritic. The sands are normally incoherent and lack any cementing material other than limonite, but some beds, the so-called ‘sand rock’, contain a high proportion of carbonate. The uppermost part of the Yellow Sands, lying immediately below the Marl Slate Formation, are also characteristically cemented in this way. The name Yellow Sands was first given by Hutton in 1831 following pioneering work by Sedgwick. The western and southern edges of the Permian desert in which the sands were being deposited were fringed by rocky uplands. Breccias derived, from these uplands, and deposited at the same time as the Yellow Sands are present in the south

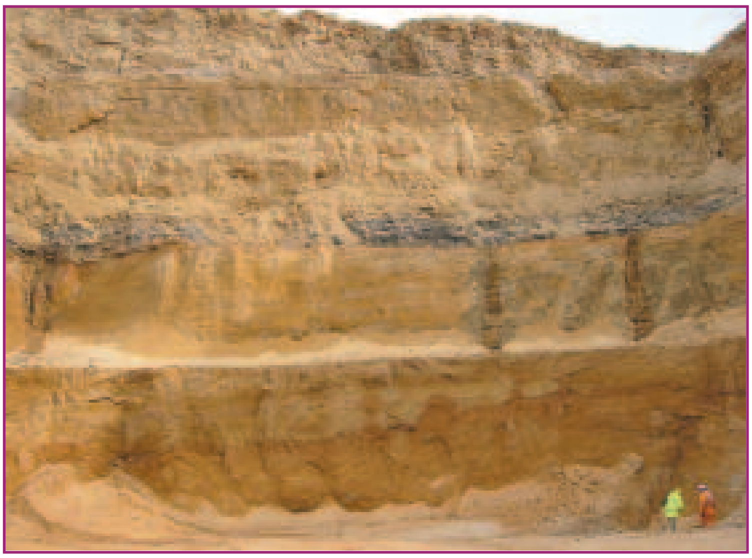


Photo 23. Hepplewhites Quarry, Quarrington. Yellow Sands overlain in turn by Marl Slate (grey) and Raisby Formation.

of the county east of Bishop Auckland. The breccias are highly variable in composition and range from rocks containing small angular fragments of Carboniferous mudstone, sandstone or limestone to breccio-conglomerates. The Lower Permian breccias are patchily distributed in the south of Durham.

The Permian Yellow Sands crop out intermittently along the base of the Magnesian Limestone escarpment and dip to the east beneath the limestone. At outcrop the formation is clearly discontinuous and forms ridges of various heights. When they were deposited, the sands formed hills on the land surface and the crests of such hills have been visible in a number of exposures within the county. The ridges, which probably represent accumulations of sand dunes, are typically between one to two kilometres wide with sand thicknesses of up to almost 70 metres and are separated by belts where the sands are thin or absent. The absence of suitable sub-surface information for much of the county makes it impossible to predict accurately where they occur, although it is generally accepted that they occur in west-south-west to east-north-east trending ridges which continue beneath the limestone for some distance. The exact nature of the dunes has been the subject of much discussion and is still a topic of research.

The unconformity between Permian and Carboniferous rocks, at the base of the formation, has only been exposed at a few localities within the county, mainly in the Bishop Auckland area.

Influence on the landscape

Owing to its very limited outcrop, the Yellow Sands Formation generally has little effect on the landscape, though the sands are locally exposed in several working and abandoned quarries.

Influence on biodiversity

Surface exposure of the Yellow Sands is so restricted that they do not generally have any significant influence on biodiversity, though in both active and abandoned quarries they locally support a flora of sand-loving species.

Economic use

The Yellow Sands comprise a resource of fine aggregate and, because of their regular grain size, are mainly worked as a source of building sand, with some also being used as asphalting sand. Resources at outcrop are limited and the sands area now worked mainly in association with the overlying Magnesian Limestone both at the escarpment edge (e.g. Crime Rigg Quarry) and where they have been exposed in the floor of quarries, (e.g. Thrislington and Raisby). Among the more unusual uses for the sands is as a surface for greyhound tracks.

Future commercial interest

Continued working of economically recoverable sand must be expected.

Environmental considerations

The highly porous nature of the Yellow Sands means that, where they are sufficiently thick, they provide a major aquifer and are important sources of groundwater. They have been tapped by many wells and boreholes. One cubic metre of Yellow Sands can hold 95 to 200 litres of water. It is also an important factor in considerations of landfilling of abandoned quarries where the formation is exposed or present beneath the base of the quarry. The large quantities of water within the Yellow Sands initially posed a major obstacle in the sinking of shafts through Permian rocks to reach the Coal Measures. Solutions to the problem, including large-scale pumping or freezing of the ground, were costly and time consuming. Coal working beneath the

Magnesian Limestone and Yellow Sands needed to ensure the preservation of a minimum thickness of rock between the planned working and the waterlogged deposits. Exploration boreholes had to be sunk with care to avoid large quantities of water flowing into the working places. Many collieries had their effective working lives terminated by the cost of either pumping water from the workings or the need to leave large areas of potential reserves untouched to avoid the risk of flooding.

Wider significance

The well-preserved sand dunes, and their internal structures, give important evidence of Permian desert environments. The Yellow Sands are an important reservoir for oil and gas beneath the North Sea. Studies of the ancient sand dunes onshore within the county has enabled geologists to understand and predict the likely properties of the rocks as hydrocarbon reservoirs.

Selected References

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1994, 1995; Smith and Francis, 1967; Smith et al. 1974; Smith et al. 1986.

MARL SLATE FORMATION

The Marl Slate, well known since the works of Sedgwick and Hutton in the 19th century as the equivalent of the Kupferschiefer (Copper Shale) of Germany, is the first widespread deposit of the Zechstein Sea. Because of its distinctive and abundant fauna and flora and its unusual content of metallic elements, the formation has been studied in great detail. It was deposited in Lower Permian Times, about 240 million years ago.

The Marl Slate Formation in Great Britain

The Marl Slate can be traced throughout the entire length of the marine Permian outcrop in North-East England. It stretches from north Nottinghamshire, through central and east Yorkshire, County Durham and into the North Sea.

The Marl Slate provides a unique glimpse of the natural history in and around the margins of the Zechstein Sea some 240 million years ago. The unusual lithology and faunal content of the Marl Slate Formation has prompted alternative models for its mode of formation, either as a shallow water lagoonal deposit, or as the deposit of a deeper water basin. The prevailing view is that the Marl Slate was deposited in a barred basin perhaps 200 to 300 metres deep over wide areas. Water depths were probably particularly varied in eastern County Durham where local sea-floor relief resulted from the flooding of pre-existing Yellow Sand ridges. It is also generally accepted that the lower parts of the Zechstein sea at this time were stagnant.

The Marl Slate Formation in County Durham

The Marl Slate Formation is a laminated, commonly bituminous, silty, argillaceous dolomite with an unusually high concentration of metallic minerals and a distinctive fish, and more rarely reptilian, fauna. Rare plant fossils have been found locally. It represents a rapid marine transgression At outcrop it is a dark yellowish orange or yellowish brown commonly fissile rock, but where unweathered it is hard and compact, with alternating grey and black laminae. When freshly fractured, it smells of oil. It is locally interbedded with thin beds of dolomite and dolomitic limestone.

The well-established name Marl Slate was applied to the formation in the 19th century, although in strict geological terms the rock is neither a marl, nor a slate. The Marl Slate in places includes rounded sand grains and minerals such as sphalerite, galena and

Photo 24. Old Quarrington Quarry, Quarrington Hill. Marl Slate resting on Yellow Sands.

chalcopyrite. It has been suggested that some of the fish remains from the south Durham outcrop may be associated with syngenetic mineralisation.

The Marl Slate is present beneath the Magnesian Limestone throughout County Durham. It is thickest, locally exceeding 3.6 metres around Ferryhill and Quarrington Hill, but thins in places to less than 1 metre.

Influence on the landscape and biodiversity

Owing to its limited thickness and outcrop the Marl Slate Formation has very limited influence on the landscape or biodiversity.

Economic use

The Marl Slate in County Durham is nowhere of economic interest

Wider significance

The Marl Slate is well known for its fauna of fossil fish. It has also yielded important fossil reptiles and plants. Permian fossil fish faunas are very limited in number and distribution world wide. Relatively well-preserved and locally numerous examples from the Kupferschiefer of Germany attracted attention early in the 19th century. Those in the Marl Slate of County Durham were discovered at about the same time and were described a little later. In the past well-preserved specimens were collected from localities such as the Ferryhill Gap and from quarries along the escarpment and there are internationally important collections of the fossils in numerous museums. The quarries south of Middridge have been the source of the best-preserved Permian plants found in England. The railway cutting north of Ferryhill is the type locality of the plant *Mixoneura huttoniana* (King) (*see Fossils and Palaeontology*).

Selected References

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1994, 1995; Smith and Francis, 1967; Smith et al. 1974; Smith et al. 1986.

THE MAGNESIAN LIMESTONE

The Magnesian Limestone is the traditional name which has been applied to a sequence of rocks above the Marl Slate. The name Magnesian Limestone has been discarded in recent formal geological publications. However, as no direct equivalent has been proposed, the name has been retained in this report in order to inform and complement its continued use in a host of biodiversity and other reports.

It is important to differentiate between the geological unit the Magnesian Limestone and the rock type 'magnesian limestone'. The Magnesian Limestone contains a variety of rock types, mainly limestones of different compositions including magnesian limestone and may contain distinctive species of fossils.

Whereas true limestones are rocks composed predominantly of the mineral calcite ($CaCO_3$), many contain magnesium, most commonly as the mineral dolomite ($CaMg(CO_3)_2$). Limestones are named on the basis of their dolomite content thus:

limestone	0-10% dolomite
dolomitic limestone	10-50% dolomite
calcitic dolomite	50-90% dolomite
dolomite or dolostone	90-100% dolomite

It is important to appreciate that the term 'dolomite' is applied to both the mineral dolomite ($CaMg(CO_3)_2$), and a carbonate rock containing between 90 and 100% of this mineral.

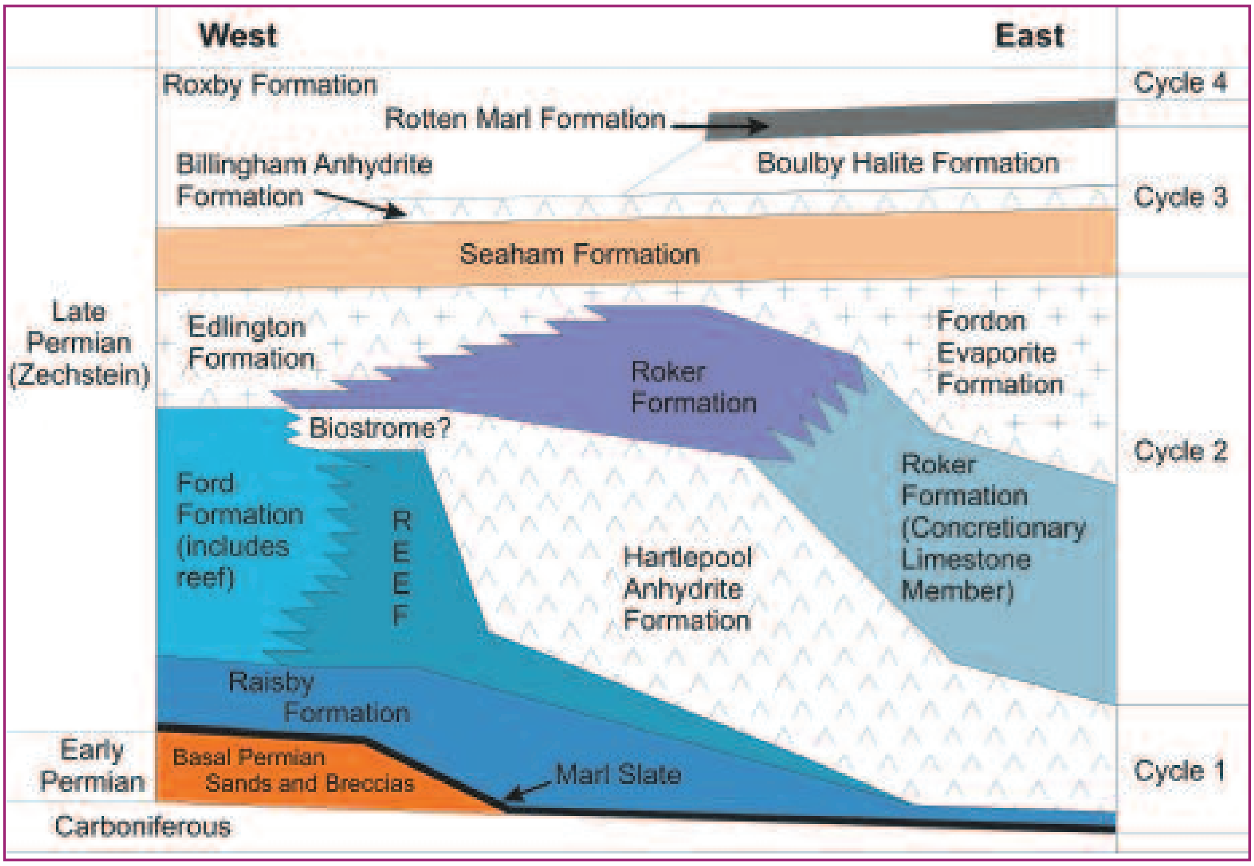


Figure 19. Schematic cross section through Permian rocks of County Durham (after Smith et al., 1986)

The Magnesian Limestone is made up of the following formally-defined geological units:

- The Rotten Marl
- The Seaham Formation
- The Seaham Residue and Fordon Evaporite Formation
- The Roker Dolomite Formation (includes the Concretionary Limestone Member)
- The Ford Formation
- The Raisby Formation

The Raisby Formation (formerly known as the Lower Magnesian Limestone)

This lowest division of the Magnesian Limestone includes rocks which range in composition from yellow or cream dolomites to almost pure, grey limestones, though the latter are rare. Three main lithological units, distinguished by colour, bedding thickness, texture and compositional variations can be recognised in many areas. The middle unit is the one most commonly seen; it is a sparingly fossiliferous hard rock with a characteristic mottling rarely found in other parts of the Magnesian Limestone. Lower units of the Raisby Formation are more regularly bedded and, on the whole, slightly coarser grained. Laminated argillaceous layers, commonly of brown clay, are present especially near the base of the sequence. Fossils are rare in the upper unit, but are locally common in the lowest unit. Calcite-lined cavities are characteristic of many sections and may represent the replacement of original evaporite minerals.

The formation has only a narrow surface outcrop, which is mainly drift free or only thinly drift-covered, commonly along an escarpment 30 to 60 metres high, but it extends beneath younger strata to the eastern edge of the county. The Raisby Formation is a major source of aggregate.

The Raisby Formation was deposited on a shelf sloping gently eastwards into the Zechstein Basin. During deposition of the limestone this slope was the cause of instability and at times there were minor submarine "avalanches" or slumping of partly lithified sediment which moved downslope. The chaotic and often contorted rock structures produced by such slumping can be seen locally in the rocks of the Raisby Formation.

The type Section is in Coxhoe Quarry (formerly known as Raisby Quarry).

At Thickley Quarry the lowest beds of the formation, which comprise thick-bedded dolomitic limestones, are overlain by fossiliferous limestone texturally similar to those at Raisby Hill Quarry. At Raisby this unit is 30 metres thick; at Thickley it is only 1 metre thick.

Photo 25. Thrislington Quarry, Ferryhill. Dolomitic limestone with cavities, characteristic of part of the Raisby Formation.

The Ford Formation (formerly known as the Middle Magnesian Limestone)

The Ford Formations displays a varied sequence of dolomites deposited in three distinct environments: shelf-edge reef that separates a broad belt of back-reef and lagoonal beds to the west from a belt of fore-reef talus aprons and off-reef beds to the east.

Photo 26. Hesleden Dene. Algal domes in Magnesian Limestone.

The barrier reef of the Ford Formation is perhaps the best known feature of the Durham Upper Permian. Most of the reef consists of massive unstratified rock which in places is at least 100m thick. It is composed predominantly of the skeletons of marine animals known as bryozoans along with many shells, some sea urchins and rare corals. Dolomites and dolomitic limestones of reef-facies crop out in a sinuous belt extending south-south-eastwards from Down Hill near Sunderland towards West Hartlepool. This has locally been much more resistant to erosion than adjacent bedded rocks and in places forms distinct topographic features such as Beacon Hill near Easington.

Photo 27. Blackhall Rocks. Caves in Ford Formation.

It is not always easy to distinguish where the Raisby Formation ends and the Ford Formation starts.

Rocks of the lagoonal type occupy most of the Ford Formation outcrop. They consist of a thick series of granular, oolitic and pisolitic carbonate rocks which are almost universally dolomitized. In most of these rocks the dolomite has recrystallised into platy crystals up to 5 mm across which give rise to a texture referred to as 'felted' and which is virtually confined to these lagoonal beds within the Ford Formation.

Not all of the rock types of the formation are well exposed within Durham. Many are better displayed immediately to the north in the Sunderland area. However, a number of the classic reef exposures to the north of the county have now been obscured. One of the largest exposures of late Permian reef-rocks in North-East England is at Hawthorn Quarry. An unusual algal-laminated dolomite, known as the Hesleden Dene Stromatolite Biostrome, overlies the top of the reef at Hawthorn Quarry. It has a boulder conglomerate at its base. The biostrome is named from its occurrence further south in Hesleden Dene. It is also very well exposed at Blackhalls Rocks.

The Roker Formation (Hartlepool and Roker Dolomites)

The Roker Formation consists of thin-bedded and flaggy cream finely granular dolomite and oolitic dolomite. It includes the well-known 'Concretionary Limestone', now formally defined as the Concretionary Limestone Member of the Roker Formation.

The Concretionary Limestone is by far the most varied carbonate unit of the English Zechstein sequence. Its best known feature is a range of calcite concretions which are spectacularly developed in the Sunderland area in the 'Cannon-ball Rock'. In coastal exposures in Durham the Concretionary Limestone falls into a lower group of beds containing abundant concretionary structures and an upper group in which such structures are generally absent. The lower beds are often so laterally variable that exact correlation of adjacent sections is difficult and the concretions lack the wide range of forms found in the Sunderland area. The formation is composed mainly of thinly bedded granular dolomites of silt- to fine-sand grade, but the rock is locally recrystallised and in some places contains many concretions. When freshly broken these rocks usually smell strongly of oil. In all onshore areas the Concretionary Limestone has foundered and lower beds have suffered varying degrees of collapse brecciation due to the solution of the underlying Hartlepool Anhydrite.

The widespread 'Flexible Limestone', commonly present slightly below the middle of the member, is a thin laminated unit which locally can split into flexible paper-thin sheets. It yielded fish remains in the Sunderland district, but none is known from County Durham. Plant debris is locally common.

The Concretionary Limestone Formation is exposed in coastal cliffs north of Seaham and intermittently in coastal exposures around Easington Colliery, and from Horden to Blackhall Rocks. Inland it is seen in Castle Eden and Nesbitt denes. Small calcareous concretions occur in the cliffs north of Loom [NZ 444 443] and south of Blue House Gill thin-bedded dolomitic limestones contain abundant concretionary structures [NZ 4682 3941] and in the upper part of the cliffs at Limekiln Gill [NZ 477 382] some bedding planes contain the worm *Tubulites.*

In those parts of Durham where the Concretionary Limestone is not developed, the Roker Formation consists of beds of dolomite and oolitic dolomite. It is exposed in the coastal cliff section near Cross Gill, Blackhalls Rocks [NZ 4756 3821], where the topmost part consists of oolitic dolomite. Rocks of the Roker Formation also form a series of isolated outcrops between slipped masses of glacial deposits for about 410 metres on the north side of Dene Mouth [NZ 457 408]. Inland it is exposed on the south side of Castle Eden Burn with limited exposures in Nesbitt Dene and Hardwick Dene.

The Seaham Formation

Although highly variable, the Seaham Formation is the most uniform of the Late Permian carbonate units. It consists predominantly of thin-bedded limestone with some dolomite, but in places may resemble the Concretionary Limestone.

The formation carries a unique and distinctive diagnostic assemblage of algae and bivalves. Small tubular, stick-like remains of the probable algae *Calcinema permiana* are present in great abundance. The Seaham Formation is exposed mainly in coastal cliffs at Seaham, but is also patchily exposed inland in Seaham Dene. Its type exposure is in the sides of the dock at Seaham Harbour.

The Rotten Marl

The Rotten Marl is a dull dark red-brown silty mudstone, which in borehole cores contains scattered halite crystals and a network of veins of fibrous halite and gypsum. It occurs in situ only south of the county and offshore. It was exposed within the filling of a breccia pipe, or fissure filling, at the top of the north wall in Seaham Dock, but has now been largely obscured.

Influence on the landscape

The Permian rocks of East Durham form a low upland plateau of Magnesian Limestone sloping gently eastwards to the sea and southwards to the Tees plain, and defined in the west by a prominent escarpment. The soft Permian rocks that underlie the plateau are locally well exposed on the escarpment and at the coast, but elsewhere are covered by a mantle of glacial drift. The topography of the plateau is gently undulating and is deeply incised in the east by coastal denes. The coastline is one of clay-crested limestone cliffs, giving way in the south to low dunes, with a foreshore of sandy beaches and rock outcrops heavily disfigured in the north by tipping of coal wastes.

Photo 28. Quarrington. The escarpment of the Magnesian Limestone.

The escarpment and parts of the plateau have also been affected by the quarrying of limestone. Large active and disused quarries occupy prominent sites on the escarpment. A number of older quarries that have naturally re-vegetated are managed as nature reserves.

The landscape is generally open and broad in scale although the plateau terrain rarely affords long distance views. From the higher ground of the escarpment there are panoramic views across the Wear lowlands to the Pennine fringes beyond, and south across the Tees plain to the Cleveland Hills. The landscape of the plateau has been heavily influenced by urban and industrial development and its scattered mining towns and villages and busy roads locally give it a semi-rural or urban fringe character.

The Magnesian Limestone, though widely covered by drift, has exerted a profound effect on both the natural and social history of eastern Durham. Exploitation of the huge coal reserves concealed beneath the Magnesian Limestone began early in the 19th century. Coincident with this mining activity came the development of numerous colliery settlements.

Influence on biodiversity

The grasslands that have developed on soils derived from Magnesian Limestone form an important variant of calcareous grassland, which is unique to North East England, with the majority of the remaining resource, approximately 225 hectares, occurring in County Durham. The most significant sites include the National Nature Reserves at Thrislington and Cassop Vale where primary Magnesian Limestone grassland still occurs. Other statutory sites display secondary grassland where species of interest have colonised the rudimentary soils occurring within abandoned quarries.

Thrislington, in particular, is noted for its rich assemblage of interesting plant species including several southern species, such as perennial flax, growing near the northern limit of their distribution together with species of northern distribution such as blue moor grass and mountain everlasting. The dark red helleborine and the glow worm are both Biodiversity Action Plan species which also occur at this site.

The shallow calcareous soils of the steeper escarpment slopes generally have a pastoral aspect and contain areas of well-established Magnesian Limestone flora. Ash woodland or mixed broadleaved woodland with ash often dominant is developed in some of the coastal denes. Castle Eden Dene represents one of the finest examples of yew woodland in Europe.

Quarries in the Magnesian Limestone have been worked according to demand, one opening when another closes, or sometimes remaining idle for long periods. In these circumstances they have provided suitable habitats, free from competition, for colonisation by the plant species present in the unique semi-natural grasslands nearby. It is possible that the quarries which are active today will provide alternative sites in the future.

Economic use

The Magnesian Limestone has provided, and continues to provide, a wide variety of economic products.

Building Stone

It is likely that prior to 1800 the rocks of the Magnesian Limestone were used mainly for building purposes, and many of the early settlements along the Permian escarpment were built of dolomitic limestone and dolomite worked in numerous small and a few large quarries. Most of these were opened in the evenly bedded Raisby Formation which offered the most suitable building material. With the

Photo 29. Heighington. Magnesian Limestone as a building stone: the quoins are Coal Measures sandstone.

Flux

The development of iron making in North-East England has led to a demand for high calcium Magnesian Limestone to supplement Carboniferous limestone for us as a flux in blast furnaces. Extraction for this purpose started around 1850 and continued in considerable volume until about 1920 when the iron makers began to substitute high magnesian limestone for high calcium limestone in their furnaces. Among the quarries worked were Raisby Hill, Wingate, Tuthill, Bishop Middleham and Hawthorn. The use of magnesian limestone as a flux continues to this day.

exception of the reef-rock, which has been used on a small scale in buildings at Hawthorn, Easington, Peterlee and Hesleden, the dolomite of the Ford Formation is usually too soft and variable for building purposes.

Agricultural lime

There is historical evidence that the Magnesian Limestone was being quarried in earnest in Durham for lime burning in the mid to late 18th century. With the increasing use of lime for agricultural purposes in the early part of the 19th century a number of quarries in the Raisby Formation and some new ones, including the large Tuthill Quarry in the Ford Formation near Haswell, supplied burnt or ground lime. High calcium 'magnesian limestone' was burnt at Coxhoe and Ferryhill Station for many years and probably also at Hawthorn, Running Waters and Bishop Middleham. The introduction during the Second World War of the Agricultural Lime Scheme encouraged much greater use of lime in agriculture and there has been a trend towards the use of ground magnesian limestone, where readily available, instead of the more traditional burnt or ground limestone.

Dolomite refractory

When the Bessemer & Siemens system for the bulk production of steel was developed in 1850/60 local iron ores could not be used. These ores contained a relatively high proportion of phosphorus and sulphur which attacked the steel furnace-lining when incorporated in the slag formed in the melting process. This problem was resolved with the development of a refractory lining capable of withstanding chemical attack from the basic steel slag. Although lime was chemically suitable it lacked physical stability and it was discovered that a certain type of magnesian limestone (normally a true dolomite) when dead burnt, provided excellent refractory properties both chemically and physically. The production of "basic bricks" at Leasingthorne using Magnesian Limestone from Westerton Quarry, Bishop Auckland, was recorded in 1884. Commercial kilns, "cupolas", for the production of dead burnt Magnesian Limestone were built at Raisby. The product known as "basic" was later given the commercial name "Doloma". Coxhoe and Joint Stocks Quarries saw the biggest development in the production of

Doloma. By 1920 Doloma was being produced at Coxhoe, Raisby and Cornforth quarries.

Magnesia and Magnesite

In 1844 Magnesia (magnesium oxide, MgO), was produced by the Washington Chemical Co. under the leadership of H.G. Pattison, one of the greatest industrial chemists of his day. By 1870 his relations had patented the process of making basic magnesium carbonate or magnesite ($MgCO_3$) and magnesium oxide from dolomite using magnesian limestone from the Hylton Quarry at Sunderland. Magnesia has been produced in Darlington for pharmaceutical and insulation products since 1928. Magnesian limestone, mainly from Aycliffe quarries, was used until the 1970's when the process was changed to use calcined dolomite from Thrislington Quarry.

In 1937 the opening at Hartlepool by the Steetley Company of a plant to manufacture a magnesite product from dolomite and seawater marked an important development in the use of magnesian limestone. Known as the Palliser Works, the plant relied on regular and steadily increasing supplies of dolomite lime, 'Dolime' from Coxhoe Quarry. As recently as 2003, Dolime, for the plant was being supplied from Thrislington Quarry. Magnesia (magnesium oxide, or MgO) has exceptional properties of electrical resistance and heat conductivity which makes it the preferred insulation material used in the manufacture of domestic and industrial heating elements.

Construction

The construction industry has become the dominant market for magnesian limestone since the mid 1960's. Although not the most suitable

Photo 30. Coxhoe (Raisby) Quarry. Dolomitic limestone of the Raisby Formation.

aggregate for construction, magnesian limestone has been used very successfully for bulk fill and hardcore and, after careful selection, for roadstone, drainage systems and the coarse aggregate for concrete production. It has also been used for the surfacing of running tracks and, before the advent of Astroturf, the hard porous areas for football and hockey pitches. At Raisby the Magnesian Limestone of the Raisby Formation was used for the manufacture of Tarmacadam. The construction boom in the Tyne Tees area over the decade 1965-1975 saw the reopening of a number of old workings which had existing planning permission. Among the quarries reopened were Tuthill near Easington, Hawthorn Quarry, Haswell Moor Quarry, Hart Quarry, Bishop Middleham Quarry and Stonegrave Quarry at Aycliffe.

Lime for use in mortar has also been obtained from the Magnesian Limestone.

Future commercial interest

Continued working of Magnesian Limestone for its present uses can be expected.

Environmental issues

Widespread underground coal extraction has taken place beneath the Magnesian Limestone of much of the county. During active mining, surface subsidence, in part facilitated by the well-developed system of joints within the limestone, was a common phenomenon, often requiring remedial work to affected structures and land. Since the ending of underground mining, surface subsidence has continued in a number of locations previously affected by such instability. There is also evidence of instability in areas not previously known to have been so affected. Recent research indicates a close spatial relationship between such collapse features and faults which cut the limestone and underlying Coal Measures. Observed features are consistent with some form of renewed subsidence or reactivated fault movement, perhaps related to rising groundwater levels in the Coal Measures rocks. The presence of such areas of known or potential instability need to be taken into account in all aspects of land-use planning across the Magnesian Limestone outcrop. Particular attention needs to be directed towards the management of present and future land-fill sites and the siting of major structures and services. Further studies of these phenomena, and their potential environmental impact on the County are recommended, especially in the light of proposals to discontinue, or modify, pumping of groundwater in the coalfield.

Selected References

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1994, 1995; Smith and Francis, 1967; Smith et al. 1974; Smith et al. 1986.

Geological SSSIs

SSSI Name	GCR Name	Grid Reference
Crime Rigg And Sherburn Hill Quarries	Crime Rigg Quarry	[NZ 344 416]
Durham Coast	Blackhalls Rocks	[NZ 468 395]
Durham Coast	Seaham Harbour	[NZ 430 499]
Hawthorn Quarry	Hawthorn Quarry	[NZ 435 463]
Middridge Quarry	Middridge Quarry	[NZ 252 252]
Raisby Hill Quarry	Raisby Hill	[NZ 346 354]
Stony Cut, Cold Hesledon	Cold Heseldon	[NZ 417 472]
Trimdon Lime-stone Quarry	Trimdon Grange Quarries	[NZ 361 353]
Yoden Village Quarry	Yoden Village Quarry	[NZ 436 417]

Permian rocks are also exposed within a number of areas scheduled as SSSIs, but not specifically designated for Permian rocks within the Geological Conservation Review.

Durham County Geological Sites

Bishop Middleham Quarry	[NZ 3331 3332]
Dene Holme	[NZ 454 404]
Old Quarrington Quarry	[NZ 32 38]
Townfield Quarry, Easington Colliery	[NZ 434 436]
Castle Eden Dene	[NZ 4223 379 – NZ 440 400]
Ferryhill Gap	[NZ 30 34 – NZ 30 32]
Hesleden Dene and downstream continuation	[NZ 434 388 – NZ 469 370]
Old Towns Quarry	[NZ 257 256]
Raisby Railway Cutting	[NZ 345 350]
Rough Furze Quarry	[NZ 317 326]
Beacon Hill and Beacon Hill Rail Cutting	[NZ 443 455]
Thrislington Quarry	[NZ 310 330]
Chilton Quarry	[NZ 300 314]
Middridge Railway Cutting	[NZ 250 251]

INTRUSIVE IGNEOUS ROCKS

Intrusive igneous rocks are those which have formed by being intruded (emplaced) as molten rock, or magma, into the surrounding rocks. They are distinguished from volcanic, or extrusive igneous, rocks by having crystallised and cooled at depth within the earth's crust. Such intrusions may take a number of forms, including widespread more or less horizontal sheets, known as sills; more or less vertical sheet-like bodies, known as dykes; and very large, often rather irregular, bodies known as batholiths. Intrusions may be of various geological ages. Intrusive igneous rocks, of a great variety, compositions, ages and forms are extremely common in parts of Great Britain.

Intrusive igneous rocks, which are exposed at the surface due to millions of years of erosion, give vital information on a great variety of geological processes which have operated deep within the earth's crust over many millions of years of earth history. A variety of sophisticated analytical techniques can be used to date the crystallisation of certain minerals within these rocks. These dates, when interpreted along with other geological evidence, provide an extremely valuable means of assigning accurate dates to key events in earth history.

Intrusive igneous rocks in County Durham

Outcrops of Intrusive Igneous rocks comprise approximately 2,523 hectares, or about 1%, of the surface area of County Durham (*Figure 20*).

Intrusive Igneous rocks of several ages and compositions occur within the county.

One major intrusion, the Weardale Granite, does not reach the surface and has been proved only in the Rookhope Borehole, but has been a major

Photo 31. Copthill Quarry, Cowshill, Weardale. Abandoned quarry in Whin Sill adjacent to Burtreeford Disturbance.

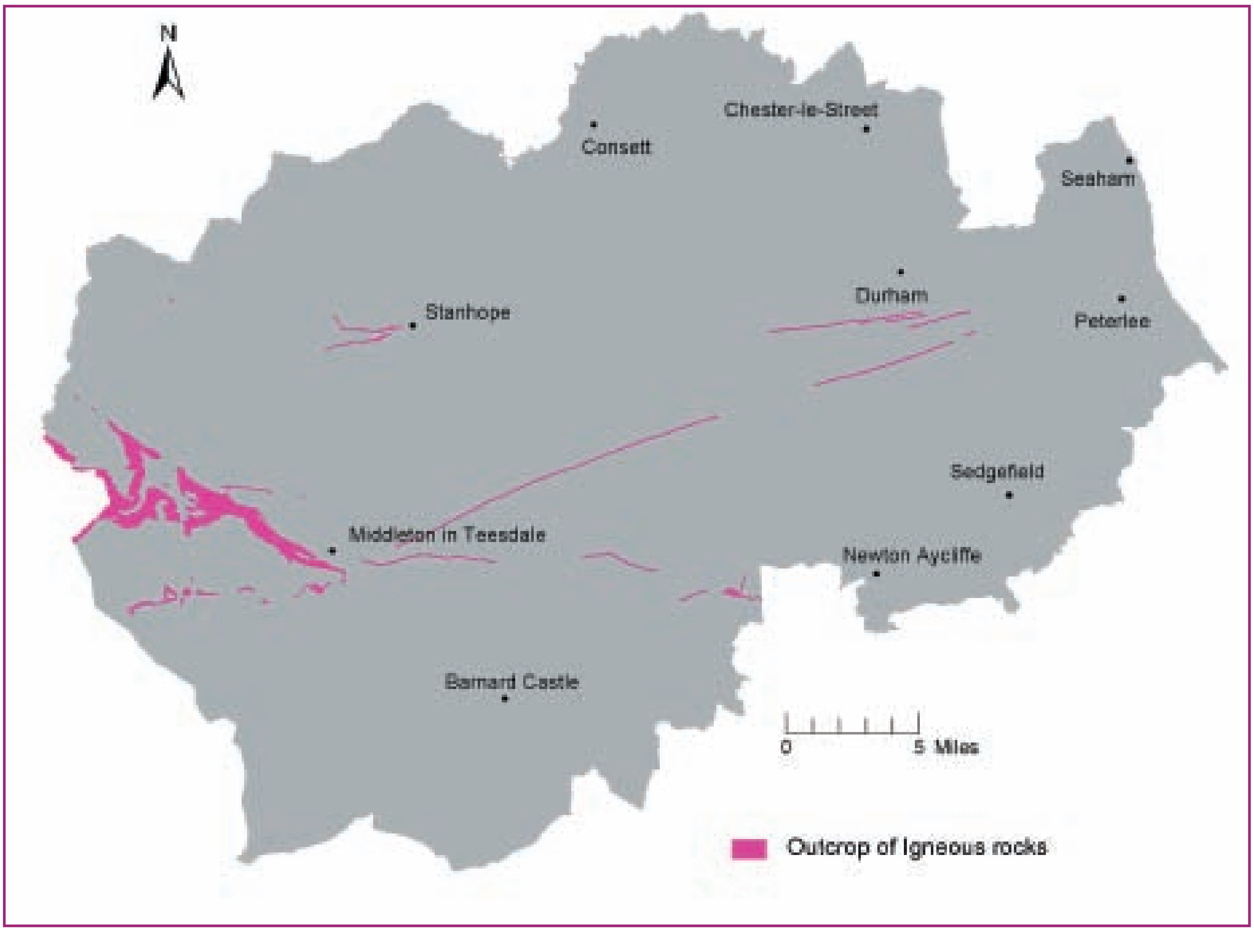


Figure 20. Distribution of intrusive igneous rocks in County Durham

factor in the geological evolution of the north of England (see *The Geological Evolution of County Durham*). The term 'minor intrusion' is commonly applied to small bodies, or groups of small bodies, of intrusive igneous rock.

The intrusive igneous rocks of the area are reviewed briefly according to their ages of emplacement.

Caledonian intrusions

These rocks were emplaced during the long and complex series of earth movements which affected the area that was to become the UK, between roughly 500 and 390 million years ago. Within County Durham it is possible to recognise two groups of intrusive igneous rocks which date from this period.

The Weardale Granite

The pattern of mineralisation in the Northern Pennines, and comparisons with areas such as SW England, together with geophysical evidence, led to speculation that a concealed granite might be present at depth beneath the North Pennines. This hypothesis was tested in 1960-61 with the drilling of the Rookhope Borehole which proved granite at a depth of 390.5 metres. However, as the granite proved to have a weathered top, it was clearly much older than originally supposed. Radiometric dating of the granite gives it a geological age of crystallisation of 410 ± Ma, proving it to be a Caledonian intrusion.

Geophysical studies suggest that the Weardale Granite is part of a very large concealed batholith, which is likely to be some 60 by 25 kilometres in extent. These same studies suggest that the batholith has several high spots, or cupolas, on its upper surface which reach within a few hundred metres of the surface at such places as Rookhope, Rowlands Gill, Tynehead and Scordale.

Caledonian minor intrusions

Within County Durham, minor intrusions of Caledonian age are represented by the lamprophyre dykes which cut the Ordovician Skiddaw Group mudstones at Pencil Mill, near Cronkley in Upper Teesdale.

Permo-Carboniferous basic sills and dykes - the Whin Sill Suite

In late Carboniferous times and early Permian times, widespread earth movements beneath the area that eventually became Great Britain, caused fracturing and extensive stretching of the crust, allowing huge quantities of molten rock, or magma, to rise from deep within the Earth. In Northern England this magma did not reach the surface, but spread widely as sheets between the layers of pre-existing rocks, where it slowly cooled and crystallised to form the largest and most extensive suite of intrusive igneous rocks in Northern England, collectively termed the Whin Sill or the Great Whin Sill.

The intrusion of such large volumes of molten rock, at temperatures in excess of 1000°C had profound effects upon the surrounding rocks, causing widespread intense alteration, or metamorphism, with the development of a range of distinctive metamorphic minerals and textures. A variety of hydrothermal minerals formed as joint fillings during the final cooling stages of emplacement of these intrusions.

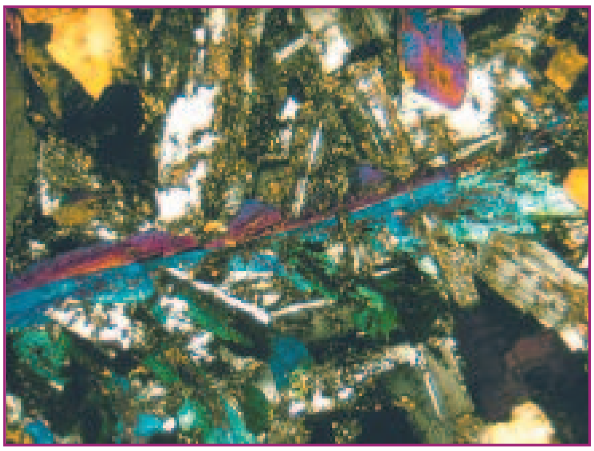


Photo 32. Thin section of Whin Sill dolerite pegmatite from High Force Quarry, Teesdale.

The Great Whin Sill

This complex underlies much of North East England, including most of County Durham. It typically comprises an extensive series of sills with some associated dykes, and is composed of tholeiitic quartz-dolerite which exhibits a remarkable continuity in mineralogical and chemical composition across its extensive outcrop. By far the greater part of the complex consists of fine-to medium-grained dolerite, though fine-grained, chilled tachylitic contact rocks are common, and very coarse-grained dolerite pegmatite veins and segregations are common locally. Crude columnar joining is conspicuous in most exposures. The sill reaches its maximum known thickness of around 70 metres in Teesdale and in West Allendale, Northumberland, a short distance north of the county boundary.

Radiometric dating reveals an age of around 295 million years for the Whin Sill. Palaeomagnetic studies reveal that at the time of its crystallisation the area lay within tropical latitudes.

The Little Whin Sill

Over much of the county the Whin Sill exists as a single roughly horizontal sheet. However, in the Rookhope and Stanhope area of Weardale a much thinner upper leaf of the intrusion, known as the Little Whin Sill is present.

Both leaves of the sill were proved in the Rookhope Borehole. The Little Whin Sill typically comprises fine- to very fine-grained dolerite similar in composition to much of the Great Whin Sill. Unlike the main sill, the Little Whin Sill dolerite is distinguished by the presence of tiny phenocrysts of olivine, or pseudomorphs after olivine, within the lowest parts of the intrusion.

Dykes associated with the Whin Sill:

Several dykes are associated with the sill, some of which may have acted as feeders during its emplacement. Several of these have been given local names in the geological literature. These include:

The Greengates Dyke
This crops out on the north side of Lunedale, Lunedale [NY 933 234].

The Connypot Dyke
This crops out in the headwaters of the River Lune [NY 813 207].

The Hett Dyke
This can be traced intermittently for many miles from exposures in the Egglestone Burn [NY 985 258] to the Bowburn area [NZ 320 383]

The Wackerfield Dyke
This is exposed locally in the Wackerfield area [NY 158 227]

The Brandon Dyke
This can be traced intermittently for several miles from near Quarry Hill, north of Brancepeth [NZ 212 389] to the neighbourhood of Shincliffe Colliery [NZ 304 401]. A second parallel dyke is present locally in the easternmost part of the outcrop.

The Ludworth Dyke
This is known, only from underground coal workings, to extend intermittently from south of Shincliffe [NZ 296 392] to the sub-marine coal workings in the Easington area [NZ 447 438].

Palaeogene intrusive rocks

During Palaeogene, or Tertiary, times, enormous earth movements associated with the opening of the Atlantic, resulted in extensive volcanic activity in the area we know today as the Hebrides and parts of Northern Ireland. In addition to the huge thicknesses of lavas which were erupted in these areas, large bodies of intrusive igneous rocks were emplaced beneath the volcanic centres. Stresses in the earth's crust at this time caused cracking of rocks to extend in a radial pattern for many miles away from the volcanic areas. As they developed deep beneath the surface, these cracks were filled with basaltic magma, forming a series of extremely long dykes, which may be traced across much of Northern England.

Cleveland-Armathwaite Dyke
Within County Durham, the most extensive group of Palaeogene intrusions is the echelon of dykes collectively known as the Cleveland-Armathwaite Dyke, which derives its name from its outcrop across northern England, from the Cleveland Hills in East Yorkshire, to Armathwaite in the Vale of Eden in Cumbria, and which forms part of a group, or 'swarm', of dykes centred on the Island of Mull.

These dyke rocks are dolerites which may be readily distinguished from those of the Whin Sill by their porphyritic character, with small phenocrysts of feldspar and pyroxene set in a dark grey fine-grained matrix. A minimum age of around 55 Ma has been established for these rocks.

A small dyke up to about 5 metres wide, in the Bolam area, close to and parallel to the Cleveland-Armathwaite dyke, has been referred to as the **Lough House Dyke**.

Photo 33. Haggerleases Quarry, Cockfield Fell, July 2003. Worked-out section of the Cleveland-Armathwaite dyke. The face on the right is in Coal Measures sandstone.

Influence on the landscape

As it does not reach the surface the **Weardale Granite** has no direct affect on the landscape character of the county. However, its buoyancy effect within the basement rocks of the Northern Pennines has long influenced the geological history of the area throughout much of Carboniferous and later time. This continued buoyancy effect partly accounts for the upland nature of the western part of the county today.

Photo 35. High Force, Teesdale. The Whin Sill here intrudes the beds above the Tynebottom Limestone.

The surface outcrop of the **Caledonian minor intrusions** is extremely limited and, apart from forming very small craggy exposures close to the river bank, their impact upon the landscape is very small.

Because of its hardness and resistance to erosion, the outcrops of the **Great Whin Sill** comprise some of the best known and most dramatic landscape features of Teesdale, in the west of the county. Most extensive of the natural exposures are the sombre cliffs of Crossthwaite, Holwick and Cronkley scars, as well as the waterfalls of High Force, Low Force and Cauldron Snout. Prominent crude columnar jointing is conspicuous in all of these natural exposures. It is also very well exposed in several large abandoned quarries along its outcrop on the southern side of Teesdale, and on the north side of the river at the long-abandoned High Force Quarry.

Photo 34. The Whin Sill outcrop at Low Force, Teesdale.

The outcrop of **The Little Whin Sill** is restricted to a small area of Weardale between Eastgate and Stanhope. The Little Whin Sill gives rise to low waterfalls in the Rookhope Burn at Turnwheel Linn, Rookhope and in Horsley Burn, near Stanhope. At Stanhope the River Wear flows through a narrow channel cut through the resistant dolerite of the Little Whin Sill. Between Eastgate and Stanhope the outcrop is marked by a low scarp feature, in which small exposures of columnar jointed dolerite are locally visible. Spectacular cliffs of columnar jointed dolerite are also present in the faces of the long-abandoned and flooded workings of Greenfoot Quarry, near Stanhope.

Dykes associated with the Whin Sill

The **Greengates Dyke** has been quarried on a significant scale at Greengates Quarry, Lunedale [NY934 236], which now comprises a conspicuous landscape feature.

Photo 36. Holwick Scars, Teesdale. Crags of columnar-jointed Whin Sill dolerite.

The course of the **Hett Dyke** may be traced in a series of old quarries, for example in the Eggleston [NY 9896 2610] and Hett [NY 280 368] areas.

The **Wackerfield Dyke** locally forms a well-marked feature in the vicinity of Tunnelmire Plantation [NZ 1732 2325], and has been quarried north-east of Wackerfield village.

The course of the **Brandon Dyke** is marked by long-abandoned quarries in the High Houghall area [NZ 2749 3965] and [NZ 2722 3954].

The **Ludworth Dyke** does not crop out at the surface and thus has no impact upon the landscape.

The impact upon landscape of the **Palaeogene dykes** today derives mainly from their former working in quarries along their outcrops. Most conspicuous are the extensive deep quarries, resembling railway cuttings, excavated in the Cleveland-Armathwaite Dyke in the Cockfield area, though landfilling operations in recent years have destroyed some of the most spectacular exposures.

Outcrops of the Cleveland-Armathwaite Dyke in the Bolam area have also been extensively quarried, though landfilling here has obliterated most exposures.

The Lough House Dyke has little impact upon the landscape.

Influence on biodiversity

Where free, or almost free, of superficial deposits, the county's intrusive igneous rocks typically give rise to rather thin acid soils. These locally support populations of bell-heather, together with heather (ling), bilberry, cowberry and some bearberry. The Whin Sill block screes may locally host parsley fern. Fissures between larger blocks of Whin Sill dolerite provide refuges for trees such as aspen, rock whitebeam and juniper, which represent relics of former woodland. At higher altitudes these blocks may provide habitats for arctic-alpine herbs.

Tall cliffs of Whin Sill provide nesting sites for a number of birds as indicated by names such as Falcon Clints and Raven Scar.

Photo 37. Bolam Quarry, Workings in part of the Cleveland Dyke, photographed 1963, now backfilled.

Economic use

The Weardale Granite has only ever been sampled in the Rookhope Borehole and has never had any economic use, though its potential as a source of feldspar for the ceramics industry was contemplated at Cambokeels fluorspar mine in the 1980's.

The hardness and roughness of the dolerite of the Great Whin Sill, the Little Whin Sill, and associated dykes, makes these good sources of roadstone and aggregate which have been worked in numerous quarries. Most conspicuous are those in Teesdale. Several substantial abandoned quarries are conspicuous in the outcrop of this intrusion between Middleton and High Force, and in the Greengates Dyke at Greengates Quarry, Lunedale. The Whin Sill within the Burtreeford Disturbance was formerly quarried at Copthill Quarry, Cowshill, and the Little Whin Sill was also worked for roadstone at Greenfoot Quarry, Stanhope. Force Garth Quarry [NY 873 282], near High Force, is the sole remaining producer of Whin Sill dolerite in County Durham.

The Palaeogene dykes have been worked as sources of roadstone and aggregate at several localities. None is worked today and many of the largest and geologically most instructive exposures have been obliterated by landfilling.

Because of their hard, intractable nature, none of the county's intrusive igneous have ever been employed as building stones except locally in dry stone walling near accessible outcrops.

Future commercial interest

The extent of future working at Force Garth Quarry [NY 873 282] is dependent upon a range

Photo 38. Force Garth Quarry, Teesdale. Working Whin Sill dolerite.

of commercial and planning considerations, though reserves of workable rock appear to be substantial.

At the time of writing no plans are known for any resumption of quarrying from abandoned quarries within the Whin Sill. Renewed working from these, or attempts to open quarries at virgin sites, seems unlikely.

Commercial interest in working of any of the county's other intrusive igneous rocks is extremely unlikely.

Working of the Weardale Granite, as discussed above, is extremely unlikely unless a revival of fluorspar mining led to working veins in the granite.

The Weardale Granite is known to be a 'high heat production' granite. Investigations into its potential as a source of geothermal energy in the 1980's did not result in commercial trials. However, interest in possible sources of sustainable, 'green', energy sources as part of long-term plans for after-use of the Eastgate Cement Works site have recently revived interest in the geothermal potential of the Weardale Granite, or sources of thermal groundwater known within the workings of Cambokeels fluorspar mine.

Threats

Natural exposures of intrusive igneous rocks are generally robust. However, abandoned quarries are at risk of becoming overgrown or degraded. Backfilling as landfill sites or as parts of other land reclamation schemes may threaten to damage or obliterate important sections. Haggerleases Quarry, Cockfield [NZ 1155 2549] and Bolam Quarry, Bolam [NZ 199 226] are good examples of sites damaged or obscured in this way. All abandoned quarries in these rocks may be perceived as 'at risk'.

Wider significance

The proving of the Weardale Granite in the Rookhope Borehole was a major contribution to understanding the geological structure of Northern England. The influence of the granite on the geological evolution of northern England extends far beyond County Durham. Its role in the formation of the metalliferous deposits of the Northern Pennines has contributed greatly to the development of hypotheses on ore genesis in this and similar orefields worldwide.

As it is regarded as the original sill of geological science, the Whin Sill may be regarded as one of the key natural heritage features within the county. It takes its name from the north of England quarryman's term 'sill' for any more or less horizontal body of rock, and 'whin' meaning a hard, intractable, black rock. The recognition, in the 19th century, of its intrusive origin, quickly led to the term 'sill' being adopted by geological science throughout the world for all concordant horizontal intrusive bodies of this sort.

The Whin Sill, and its associated intrusions, is one of the most studied geological formations within the county with a voluminous technical literature.

The Palaeogene dykes give important evidence of geological processes which operated far beyond County Durham.

Geological SSSIs

In GCR Block "Carboniferous - Permian Igneous"

SSSI Name	GCR Name	Grid Reference
Upper Teesdale	Whin Sill Exposures in Upper Tees	[NY 880 225]

These include:

Cauldron Snout, Upper Teesdale	[NY 815 286]
Force Garth Quarry (now known as Middleton Quarry), Upper Teesdale	[NY 873 282]
High Force, Upper Teesdale	[NY 880 283]
Low Force and Wynch Bridge, Teesdale	[NY 905 279]
Falcon Clints, Upper Teesdale	[NY 820 281]
Cronkley Fell	[NY 831 282 – NY 854 282]

In addition, the following important exposures of **Great Whin Sill** lie within the Moorhouse - Upper Teesdale National Nature Reserve and the Appleby Fells SSSI:

Red Sike and Widdybank Fell, Upper Teesdale	[NY 818 296]
Cow Green Reservoir, Upper Teesdale	[NY 815 294]
Holwick and Crossthwaite Scars, Teesdale	[NY 898 271 – NY 927 253]

Selected References

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1995, 1994; Smith and Francis, 1967, Smith et al. 1974; Smith et al. 1986.

Durham County Geological Sites

Caledonian Minor Intrusions:

Cronkley Pencil Mill, Upper Teesdale	[NY 848 296]

Great Whin Sill:

Greengates Quarry, Teesdale	[NY 934 236]
Horsley Burn Waterfall, Eastgate	[NY 975 384]
Killhope Burn, Copthill Quarry and Wear River at Butreeford Bridge	[NY 855 406]
Scoberry Bridge to Dine Holm Scar	[NY 910 274]
Widdybank Fell	[NY 820 290]
Wynch Bridge, Langdon Beck	[NY 820 290]

METAMORPHIC ROCKS

Metamorphic rocks are rocks which have been altered from their original condition or composition due to the effects of heat or pressure, or both. The mineral constituents of the original rock may either have been recrystallised or, more commonly, complex geochemical reactions within the rock may have produced suites of new minerals.

Metamorphic rocks may occur over very wide areas which have been greatly effected by a variety of earth movements such as mountain building events, where heat and pressure may both have been of great importance causing regional metamorphism. They are also commonly found adjoining bodies of intrusive igneous rocks, where the effects of great heat have usually been most significant.

The nature and composition of metamorphic rocks reflect the intensity, or grade, of alteration.

In most cases metamorphic rocks also reflect chemical and mineralogical changes resulting from the introduction of a variety of chemical by permeating chemically reactive fluids, a process referred to as metasomatism.

Metamorphic rocks in Great Britain

Metamorphic rocks are widespread in great Britain in a variety of geological environments. It is not feasible to depict clearly on a simplified map the distribution of metamorphic rocks within Great Britain.

The largest areas of metamorphic rocks in Britain occur within the Scottish Highlands where a great variety of different original rock types have been subjected, in some cases on several occasions in the geological past, to complex process of regional metamorphism of varying intensity or grade during widespread episodes of mountain building.Most of the older sedimentary and volcanic rocks of the Southern Uplands of Scotland, the Lake District and Central and North Wales have been subjected to widespread regional metamorphism, though of a much lower grade or intensity than that generally seen in the rocks of the Scottish Highlands.

Adjacent to very large, or very hot, bodies of magma, zones of contact metamorphism, or aureoles, can be rather extensive. The intensity of alteration typically declines with distance from the igneous intrusion. Such contact alteration may bake shales into very tough fine-grained rocks known as hornfels: limestones may be recrystallised to marbles or, if more impure, to a variety of calc-silicate bearing rock types. Metamorphic aureoles are commonly associated with all major igneous intrusions throughout Great Britain. The zones of thermal alteration adjoining smaller igneous intrusions are generally much narrower, and may be almost imperceptible adjacent to small intrusions such as narrow dykes.

Metamorphic rocks in County Durham

Outcrops of metamorphic rocks within the county cannot readily be depicted on a map of the county as they have generally not been separately mapped, typically have transitional boundaries with their unaltered counterparts, or occur in extremely narrow zones adjoining igneous intrusions.

Photo 39. Wynch Bridge, Teesdale. Raft of metamorphosed sandstones in Whin Sill.

The Ordovician mudstones and volcanic rocks in the Teesdale Inlier almost all exhibit evidence of low grade regional metamorphism and up to two phases of cleavage, mainly resulting from their involvement in earth movements and mountain-building events over millions of years. Metamorphism within these rocks has produced a number of new minerals within them, though the nature of the original rock is still evident in most cases. The most highly cleaved rocks here may be described as phyllites.

Contact metamorphic rocks occur associated with many of the intrusive igneous rocks within the county.

The largest single body of intrusive igneous rock within County Durham is the wholly concealed Weardale Granite. A substantial contact metamorphic aureole must surround the granite, though direct evidence for this is limited. Slates, reached at the bottom of a deep borehole at Roddymoor, near Crook, were found to contain garnets, thought to be a product of thermal metamorphism due to the Weardale Granite: similar rocks may be widespread in the aureole of the granite beneath the Pennines. Signs of thermal alteration in the slates exposed in the Teesdale Inlier have also been interpreted as evidence of thermal alteration due to the Weardale Granite.

Most obvious, and best developed, are the metamorphic rocks associated with the Whin Sill, especially in parts of Teesdale. In places high temperature alteration, almost certainly accompanied by the introduction of chemically active fluids (metasomatism), has altered mudstones and impure limestones to calc-silicate rich metamorphic rocks containing an abundance of minerals such as garnet, feldspar, chlorite, epidote, idocrase, diopside and magnetite. Wollastonite has been recorded from one locality on Cow Green. Elsewhere shales may have been baked to a very fine-grained hornfels or porcellanite, sometimes known to Northern Pennine miners and quarrymen as ‘whetstone’. Purer limestones may have been recrystallised to coarse-grained marbles, of which that developed from the Melmerby Scar Limestone, known locally as ‘Sugar Limestone’ is probably the most familiar. Similar, though rather less intense, metamorphic effects can be seen in the Robinson and Peghorn limestones above the Melmerby Scar Limestone. The succession of Carboniferous mudstones, calcareous mudstones, siltstones and impure limestones, which underlie the Melmerby Scar Limestone at Falcon Clints lie within the thermal aureole of the Whin Sill where they have been intensely altered to a series of calc-silicate bearing hornfels containing minerals such as garnet, chlorite, feldspar, diopside and idocrase.

Good exposures of generally rather less intensely metamorphosed Carboniferous rocks adjoining the sill are to be seen around Scoberry and Wynch bridges, also in Teesdale. Pyrite nodules within mudstones between the Cockleshell and Single Post limestones have here been altered to pyrrhotite by the thermal effects of the sill. A large xenolithic raft of sandstone, here recrystallised to a hard siliceous quartzite occurs within the sill, near Wynch Bridge.

Calc-silicate rocks containing conspicuous and abundant garnet and idocrase, developed within the limestones and mudstones of the Three Yard Limestone cyclothem, occur adjacent to the Greengates Dyke, part of the Whin Sill suite, at Greengates Quarry, Lunedale.

Significant, but less intense and much more restricted areas of contact metamorphism are associated with several of the dykes, both those of the Whin Sill suite and those of Palaeogene age belonging to the Cleveland-Armathwaite suite.

Metasomatism of Whin Sill to form the clay-rich rock known to miners as 'white whin', mainly adjacent to mineralised faults and veins, is common locally.

Very narrow zones of thermal alteration in a variety of Carboniferous sedimentary rock types adjoin a number of dykes belonging to both the Whin Sill suite and the Cleveland-Armathwaite suite.

Influence on the landscape

The landscape characteristics of the county's metamorphosed Ordovician rocks have been discussed above.

In general the contact metamorphic rocks associated with the Whin Sill and the associated dykes of this and the Cleveland-Armathwaite suite exert little influence on the present landscape.

Only in the parts of Upper Teesdale do metamorphic rocks impose any perceptible

Photo 40. Sugar limestone outcrop on Widdybank Fell, Teesdale.

characteristics on the landscape. In this area the comparatively wide outcrops of the Melmerby Scar Limestone, here altered to coarse-grained marble, is locally very well exposed forming rather rounded, water-worn, pale grey outcrops. In some of these can be seen areas of crumbly disintegration of the limestone producing the mineral soil largely made up of individual calcite crystals, which has earned this rock the local name of 'Sugar Limestone'.

Influence on biodiversity

The very limited impact of metamorphosed Ordovician rocks on biodiversity has been discussed above.

The presence of metamorphosed Melmerby Scar Limestone and the included mudstones have had a most profound effect upon biodiversity. This is most obviously seen in the vegetation. Exposures of the highly friable 'Sugar Limestone', and the quantities of it in the glacial deposits, have produced a base-rich, and in places unstable, substrate. Rendzina and Brown Calcareous soils have developed on the limestone. Where interbedded mudstones are exposed, and at the junction of the limestone with the top of the Whin Sill, base-rich gravelly flushes occur. These habitats support the 'Teesdale Assemblage' of rare plant species, relics of the more widespread late-glacial and pre-forest–maximum flora. Northern arctic/alpine species (spring gentian, alpine bistort), growing together with southern continental (hoary rockrose). As the county hosts the only English locality for some plants, as well as the most southern and northern locality for others, it is of very great botanical importance.

The relationship between plant communities and underlying bed-rock associated with the only other substantial outcrop of metamorphic rocks, the mudstones, calcareous mudstones, siltstones and impure limestones, which underlie the Melmerby Scar Limestone at Falcon Clints, seems to have attracted little or no detailed botanical research.

Economic use

The area's metamorphic rocks have attracted little economic interest.

The low grade metamorphic slates within the Teesdale Inlier were formely worked for the making of slate pencils at the small quarry at Pencil Mill, on the banks of the Tees near Cronkley. Little is known of the physical requirements which made a rock suitable for this purpose, though the comparatively soft, fine-grained nature of the slates found here, together with their pale streak, are likely to have been key factors.

Although the term 'whetstone' is locally given to metamorphosed, or hornfelsed, shale within the contact zone of the Whin Sill, no authenticated examples are known of the working of this material for the making of sharpening, or 'whetstones'.

No other examples are known of the working of any of the area's metamorphic rocks for any specific purpose.

Future commercial interest

None of these metamorphic rocks is worked today and it is extremely unlikely that any will ever attract economic interest.

Threats

Most of the better known existing exposures of metamorphic rocks are comparatively robust, though small exposures of contact rocks in long-abandoned igneous rock quarries may be at risk from obliteration due to landfilling or reclamation works.

Geological SSSIs

The following sites lie within the Upper Moorhouse - Upper Teesdale National Nature Reserve and SSSI, though the individual geological features are not specifically designated for their geological importance:

Cronkley Pencil Mill, Upper Teesdale	[NY 848 296]
Low Force and Wynch Bridge, Teesdale	[NY 905 279]
Falcon Clints, Upper Teesdale	[NY 820 281]
Cow Green Reservoir, Upper Teesdale	[NY 815 294]
High Force, Upper Teesdale	[NY 880 283]

Durham County Geological Sites

Cronkley Pencil Mill, Upper Teesdale	[NY 848 296]
Widdybank Fell, Upper Teesdale	[NY 820 290]

Selected References

Burgess and Holliday, 1979; Dunham, 1990; Johnson, 1970, 1973, 1995; Johnson and Dunham, 1963; Mills and Hull, 1976; Robinson, 1970; Taylor et al. 1971.

GEOLOGICAL STRUCTURES

Geological structures are those features which reflect the varying degrees of distortion suffered by rock units in response to earth processes. Geological structures may be viewed at a variety of scales. Minute folds and faults may be measurable on the millimetre, metre, decimetre, or even greater scales.

All rock units exhibit geological structures. These may be very simple or highly complex, depending on the degree of distortion suffered by the rocks during earth movements over geological time.

Geological structures are vital to understanding the earth processes which have shaped and modified individual rock units, and larger blocks of country, during earth history. Recording and measurement of visible geological structures enables the overall structure of an area or region to be deciphered. Such observations and deductions are fundamental to making geological maps and in predicting, exploring and working mineral deposits, including groundwater resources, and in the design of major civil engineering projects.

Geological structures in County Durham

County Durham includes numerous examples of geological structures on a variety of scales.

The county includes much of the **Alston Block.** This 'block' comprises a fault-bounded platform of Ordovician and Silurian rocks upon which the succession of Carboniferous rocks rests. Such areas are termed 'blocks' because over millions of years of geological history they have remained as more or less rigid masses affected only by comparatively modest amounts of internal faulting and gentle tilting to the east.

Photo 41. Closehouse Mine, Lunedale. The wide barytes vein adjacent to the Lunedale Fault. Photographed 1984.

This Alston Block is bounded by major fault systems on three sides, the **Stublick Fault** to the north, the **Pennine Faults** to the west, and the **Lunedale-Butterknowle Fault** to the south. The two former faults lie outside County Durham: the **Lunedale-Butterknowle Fault** crosses the southern part of the county.

Photo 42. Middlehope Burn, Westgate, Weardale. Folded Dinantian sandstones on north side of Slitt Vein.

Numerous **faults** cut the rocks of the county. These form a rectilinear, or conjugate pattern and in the west of the county many of them are filled with minerals, giving the veins of the North Pennine Orefield.

The displacement on faults in the Permian rocks is generally much less than the displacement measured where these faults cut the underlying Coal Measures. This records two phases of movements on these faults. The post-Carboniferous displacement was followed by renewed, or reactivated, post-Permian displacement. Recent research has suggested that some faults within the Magnesian Limestone may be exhibiting evidence of recent, or continuing, reactivated movement since the abandonment of underground coal mining (*see The Magnesian Limestone*).

The outcrop of Ordovician rocks surrounded by Carboniferous rocks in Upper Teesdale is known as the **Teesdale Inlier**.

The Ordovician rocks, and the Weardale Granite, were subject to millions of years of erosion prior to deposition of the Carboniferous rocks. The term **unconformity** is used to describe the erosion surface upon which these Carboniferous rocks lie. A similar unconformity at the base of the Permian rocks records the folding and erosion of the Carboniferous rocks during late Carboniferous and early Permian times.

The Alston Block is more or less bisected by a rather complex structure termed the **Burtreeford Disturbance**. This comprises an eastward facing monocline, an asymmetrical fold rather like one half of an anticline, associated along much of its length with a complex belt of faulting. Although this is poorly exposed over much of its outcrop, good small sections of steeply inclined strata can be seen locally.

Over much of the county the Carboniferous and Permian rocks are gently inclined, or **dip**, mainly to to the north, east or south. This dip is interupted in some places by 'up' folds known as **anticlines**, and 'down' folds, known as **synclines**.

The Carboniferous rocks of the Alston Block are folded into a gentle half-dome structure, sometimes referred to as the **Teesdale Dome**.

Influence on the landscape

Erosion of the very gently inclined beds of Carboniferous rock give rise to the almost flat, or gently inclined hill-tops which are so characteristic of the North Pennine landscape.

The Alston Block, bounded by major faults, is a prominent upstanding landscape feature.

Erosion of steeply-inclined Carboniferous limestones and sandstones adjacent to the Lunedale Fault in Lunedale, has produced a distinctive landscape of steep scarp and dip slopes.

The Teesdale Fault brings the Whin Sill to the surface on the south side of Teesdale where it gives rise to prominent crags such as Holwick Scars: on the north side of the valley the sill lies concealed at depth.

Some of the smaller faults, including many of the mineral veins give rise to conspicuous gully-like features in the landscape.

The Permian rocks of the east of the county form a prominent, almost continuous, west-facing escarpment above their unconformable base on the Coal Measures.

Influence on biodiversity

The geological structures themselves have little impact upon biodiversity, though the nature and disposition of the rocks affected by these structures clearly do.

Economic importance

A number of geological structures, particularly faults, place constraints upon the mining and quarrying of some rocks and minerals. This is especially so in places where faults displace, and thus effectively limit, the extent of workable rock units. Faults commonly limited the extent of underground coal workings and in places partly determined the extent and boundaries of individual collieries.

Geological structures are also of prime importance in understanding the movement of groundwater and thus are important in the assessment of groundwater resources.

Almost all of the county's mineral veins occupy faults.

An understanding of geological structure has lain at the heart of successful mining and prospecting. This understanding pre-dates the emergence of geology as an organised science: the earliest miners undoubtedly understood and applied many of the concepts and principles of modern structural geology.

Environmental issues

The importance of geological structures in constraining the working of mineral reserves has been noted above.

Ground movements associated with known faults within the Magnesian Limestone outcrop may indicate reactivated fault movement related to underground coal mine abandonment (*see The Magnesian Limestone*). Although research on this topic in relation to County durham is at an early stage, account should be taken of these phenomena when considering a wide range of engineering, land-use, waste disposal and environmental planning issues.

An accurate modern understanding of geological structures is of prime importance in relation to potential discharges of mine gases and contaminated ground water in areas of former underground workings, especially in parts of the coalfield.

Threats

Major landscape features determined by the larger geological structures, for example the Whin Sill crags in Teesdale, are robust.

Exposures of particular geological structures, for example folds and faults, are comparatively few. Examples may be seen locally in working or abandoned quarries, in stream sections and in the coastal cliffs. Those in working quarries are likely to be destroyed during quarrying. Others could be damaged or destroyed by inappropriate restoration of old workings, or by coastal erosion.

Wider significance

The major structures within the county, the Lunedale-Butterknowle fault, the Burtreeford Disturbance and the Alston Block, are all known to have had a long and complex history through geological time. Movement along these faults has influenced the Carboniferous and later geological history of northern Britain.

The conjugate pattern of mineralised faults of the Alston Block comprise the veins of the Northern Pennine orefield (*see Mineral veins and flats*).

Evidence of recent ground movement associated with faults in the Magnesian Limestone, and possibly related to coal mine abandonment, may have important implications for ground engineering and planning in other areas of abandoned underground mines.

Geological SSSIs

No geological structures are currently notified as SSSIs. However, numerous examples of geological structures occur within the extensive Moorhouse - Upper Teesdale NNR and other SSSIs within the county.

Durham County Geological Sites

Exposures of steeply inclined strata within the Burtreeford Disturbance are present at the following DCGS site:

Killhope Burn, Copthill Quarry & Wear River	[NY 855 406]

Geological structures are present at a number of other DCGS sites identified primarily for other features of interest. These include:

Cement Works Quarry, Eastgate	[NY 935 360]
Closehouse Mine, Lunedale	[NY 84 22 – NY 85 22]
Coldberry Gutter, Teesdale	[NY 940 292]
Middlehope Burn, Weardale	[NY 906 381]
Raisby Railway Cutting	[NZ 345 350]
Scoberry Bridge to Dine Holm Scar, Teesdale	[NY 910 274]

Selected references

Bott and Johnson, 1970; Burgess and Holliday, 1979; Dunham, 1990; Dunham and Johnson, 2001; Dunham and Wilson, 1985; Johnson, 1970, 1995; Johnson and Dunham, 1963; Magraw, 1963; Mills and Holliday, 1998; Mills and Hull, 1976; Smith, 1994; Smith and Francis, 1967; Taylor et al. 1971.

MINERAL VEINS AND FLATS

Mineral veins are sheet-like bodies of mineral which occupy more or less vertical cracks or fissures in the surrounding rocks, or wall-rocks. These fissures are commonly faults. Mineral veins are usually concentrated in groups in particular areas, or geological environments. The term 'orefield' is commonly applied to such concentrations of veins where they have been important sources of economically valuable minerals.

Veins **generally comprise concentrations of minerals composed of elements, which may otherwise be extremely rare or widely scattered through the rocks. Some mineral veins are composed almost entirely of one introduced mineral, though more usually a variety of minerals is present, commonly forming crude bands more or less parallel to the vein walls. Minerals present may include one or more metal ore minerals, generally accompanied by a variety of non-metallic minerals, known as gangue minerals, or as 'spar' minerals by miners.**

Flats **are roughly horizontal bodies of mineral which may extend for several metres on one, or both, sides of a vein, usually where the vein cuts limestone wall-rocks. They represent bodies of limestone, wholly or partly replaced by the minerals found in the adjoining vein, including both ore and gangue minerals. Many of the features present within the original limestone, such as bedding and sometimes fossils, may be recognisable in the flat where they are replaced by minerals.**

Mineral veins and flats in Great Britain

Mineral veins of many different types are found in many parts of Great Britain, in a wide variety of geological environments. Many of these have been important sources of metallic ores and other economically valuable minerals.

Mineral veins and flats provide clear evidence of the circulation of large volumes of warm or hot mineral-rich waters deep beneath the earth's surface. By studying their form, distribution, mineral content, chemical composition, and many other characteristics, it is possible to deduce much about the sources of the chemical elements within the deposits, their temperature and age of formation, and the geological environments in which they formed and evolved. Such investigations not only contribute to interpreting the deposits of any single area, but are also vital to understanding the nature and origins of comparable deposits elsewhere, thus helping to inform and guide exploration for similar deposits worldwide.

Figure 21. Distribution of main concentrations of mineral veins in Great Britain

Mineral veins and flats in County Durham

The veins, and associated 'flat' deposits of County Durham include part of the very large group of deposits within Carboniferous rocks which collectively form the Northern Pennine Orefield. Lead and iron minerals were the principal ores worked, though smaller amounts of zinc and copper ores were raised locally and some silver was recovered from most mines as a by-product. The non-metallic minerals fluorspar, barytes and witherite were also mined, especially in more recent years.

Photo 43. West Rigg Opencut, Westgate, Weardale. Worked out iron ore flats adjoining Slitt Vein. The vein remains as an unworked pillar in the centre of the quarry.

Veins within the county mostly occupy normal faults, typically with a maximum displacement, or throw, of only a few metres. Veins may vary from as little as a few millimetres to over 10 metres in width, though most of the veins worked have been less than 5 metres wide. The county's veins typically exhibit crude bands of more or less pure minerals roughly parallel to the walls of the veins. Non-metallic 'gangue' or 'spar' minerals such as fluorite, baryte, witherite or quartz usually comprise most of the vein, with ore minerals such as galena or sphalerite typically present as discontinuous bands or pockets within these other minerals. In some places, notably where the veins are narrow or occur between weak wallrocks such as shale, the veins may be composed largely or wholly of crushed rock fragments, known as 'gouge'.

One of a number of characteristic features of the area's veins is their close relationship to the adjacent wallrocks. In hard, or competent, rocks such as limestone, hard sandstone and Whin Sill dolerite, veins tend to be comparatively wide and to stand almost vertically. It is these areas of vein which usually proved most profitable to the miners. Workable portions of veins of this sort are known as 'ore shoots'. Between or against weak, or incompetent, wallrocks such as shales and soft sandstones, veins are generally narrow and commonly are inclined, or 'hade', at a lower angle. Such sections of vein have usually proved worthless for mining. In this area of alternately strong and weak rocks, the long, wide oreshoots between vein walls in strong beds are often termed 'ribbon oreshoots'.

In most 'flats' within the Northern Pennines the main mass of the original limestone has been replaced by a compact aggregate of crystalline ankerite, siderite or quartz, though fluorite and baryte also replace the limestone locally. Within this altered rock occur bands or pockets of the ore minerals galena or sphalerite. Many 'flats' proved to be richer in ore minerals than the adjoining vein. Cavities or 'vugs' are common in

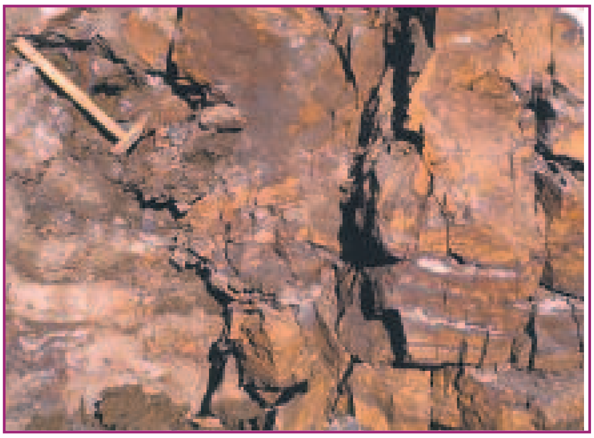


Photo 44. Ankerite and galena-rich flat in Great Limestone. Wellheads Hush, Weardale.

most 'flats' and typically are lined with well-crystallised examples of the constituent minerals.

One of the best known features of the orefield is the striking zonal distribution of certain constituent minerals within the veins and 'flats'. The deposits within a central zone, which embraces much of Alston Moor, Weardale, Rookhope, parts of Teesdale, East Allendale and the Derwent Valley, are distinguished by containing an abundance of fluorite. Outside of this zone, fluorite is generally absent, its place being taken by the barium minerals baryte, witherite, and locally, barytocalcite. County Durham includes substantial portions of the inner, fluorite zone, and a large section of the outer, barium-rich zone, which extends into the Durham Coalfield.

The veins and 'flats' are believed to have formed during one major mineralising episode after the intrusion of the Whin Sill, in late Carboniferous or early Permian times.

Millions of years of erosion since their emplacement have exposed the deposits at the surface, where weathering has altered some of the minerals. Particularly important economically has been the oxidation of large amounts of siderite and ankerite in several flats, to give large workable deposits of 'limonitic' iron ores.

The Magnesian Limestone, in the east of the county, hosts small concentrations of fluorite, baryte, galena, sphalerite and locally rare copper ores. These may, at least in part, comprise distant expressions of the main Northern Pennine mineralisation. None has proved of economic interest.

Surface exposures of mineral veins, and associated flats, may be seen at several sites

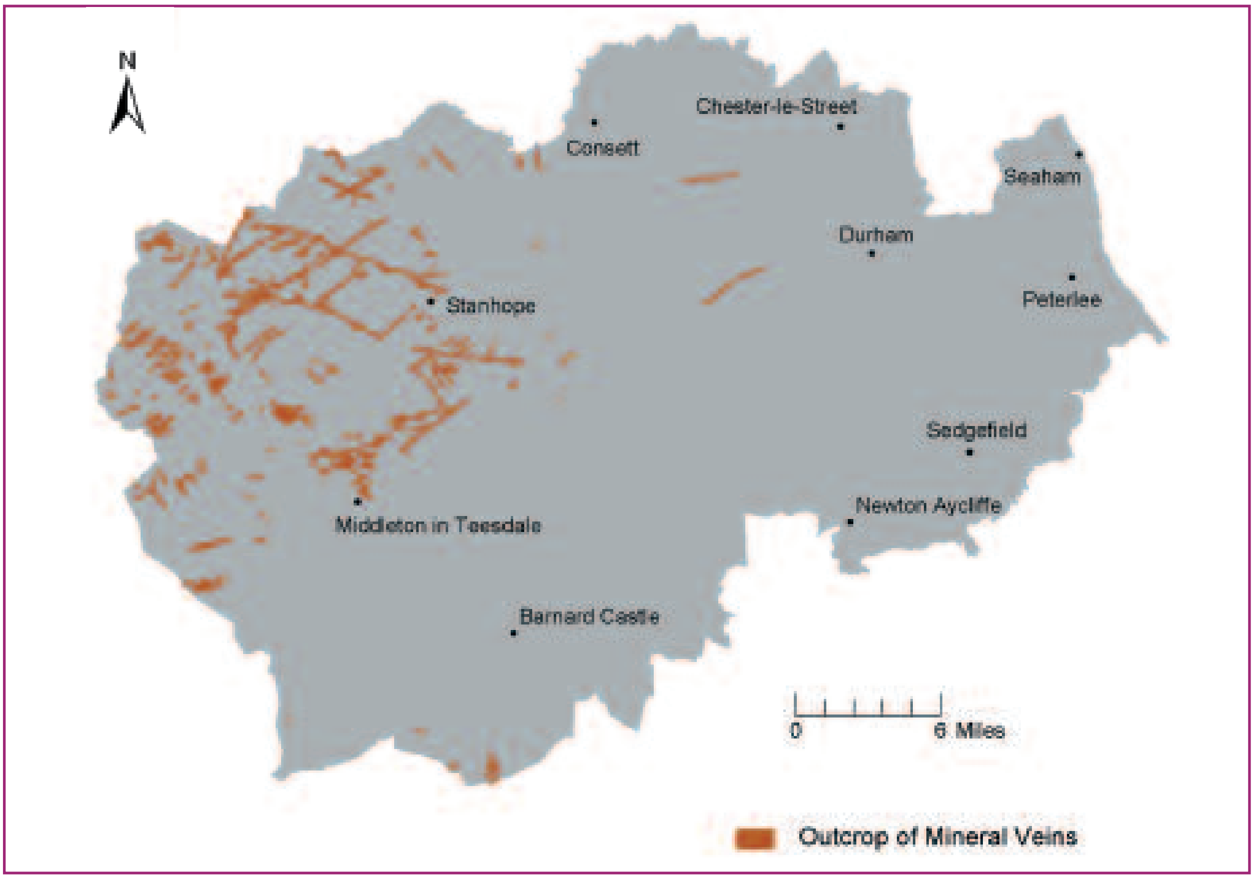


Figure 22. Distribution of mineral veins in County Durham

Photo 45. Raisby Railway Cutting, Coxhoe. Exposure of copper mineralisation in Magnesian Limestone adjoining the Butterknowle fault.

within the county. However, many of the county's most important deposits are no longer accessible and can today be understood only from contemporary reports, augmented in some instances by remaining accumulations of mine spoil. Although excellent and instructive *in situ* exposures of mineral veins and flats remain accessible underground at several abandoned mines within the Northern Pennines, only one safely accessible working remains in County Durham, at Rogerley Mine, near Frosterley.

Influence on the landscape

Despite the very small area occupied by mineral veins and associated 'flat' deposits within County Durham, their impact upon the landscape is profound. Centuries of exploitation for metal ores and other minerals have left an indelible mark upon almost every part of the physical and cultural landscape of the Durham dales.

The North Pennine Orefield is celebrated for the remains of the early form of opencast mining known as 'hushing'. This involved the periodic sudden release of torrents of water from specially constructed dams high on a hillside, above a known or likely vein outcrop. The scouring effect of the water tore away at loose surface deposits, exposing the underlying rocks and any contained mineral deposits. Large, elongated trenches, or hushes, are conspicuous features of the County Durham landscape.

By far the greater number of the county's mineral deposits were worked from adit levels, driven into hillsides, or from shafts. Stone-arched

Photo 46. Queensberry Ironstone Workings,Cowshill, Weardale. Long-abandoned and overgrown workings in ironstone flats adjacent to the Burtreeford Disturbance.

adits are common landscape features, often closely associated with spoil heaps, the remains of mine buildings and dressing floors. Many adits have today collapsed, or 'run in', and can be detected as distinctive shallow depressions in hillsides, often marked by a flow or seepage of mine water through the collapsed material. Shafts may be open, with or without protective fencing or walling, or may be seen as 'run in', sometimes water-filled, circular depressions.

Mining sites are typically marked by derelict buildings, in varying states of dilapidation, and by heaps of coarse mine spoil or spreads of fine-grained tailings.

One of the most widespread influences the county's mineral veins have had on the landscape lies in the pattern of fields and settlements. The widespread development of the dual economy of farming and mining, during the 18th and 19th centuries, resulted in the enclosure of large areas of otherwise unproductive hillside and the development of scattered, isolated settlements.

Influence on biodiversity

An important feature of the Northern Pennine Orefield is the widespread occurrence of a number of specialised plant species and communities which exhibit a clear preference for colonising soils in which there are higher than normal concentrations of heavy metals. These metallophyte and sub-metallophyte species include plants such as spring sandwort (*Minuartia verna*), alpine pennycress (*Thlaspi caerulescens*), scurvy grass (*Cochlearia pyrenaica*), mountain pansy (*Viola lutea*), thrift (*Armeria maritima*) and moonwort (*Botrychium lunaria*). One or more of these species are commonly found on, or close to, the outcrops of mineral veins. They are especially common on areas of mine spoil or tailings.

Several areas of mine spoil which remain virtually devoid of continuous vegetation cover, even after over a century, are likely to carry levels of contamination, either as high metal concentrations or as adverse soil pH values, which effectively inhibit plant growth. Striking examples of such poorly vegetated ground may be seen at the head of the Hudeshope valley, Teesdale, adjacent to the extensive workings on the Lodgesike – Manorgill Vein.

Mine water discharges may carry high levels of contaminants which can affect land immediately surrounding the discharge. Where such water discharges into streams and rivers this can have an adverse effect on the biodiversity of that watercourse. Perhaps the most notable example of metalliferous mine-water contamination of a surface stream in County Durham is the Rookhope Burn which, since shortly after the cessation of pumping at the Groverake-Frazer's Hush fluorspar mine, has carried elevated levels of elements such as iron and zinc.

Severe heavy metal contamination, apparently largely due to high lead concentrations, is a feature of soils close to a number of former lead smelting sites. In some instances small, but significant, areas of soil remain wholly un-vegetated well over a century after the end of smelting.

Influence on archaeology

There is a rich legacy of remains, in the western parts of the county, relating to the working of lead ores and associated minerals over many centuries. These remains comprise opencast workings, including hushes, spoil heaps, mine entrances and mine buildings. All have considerable historical interest. Many are scheduled, or proposed for scheduling, as historical monuments.

Economic use

The mineral veins and associated deposits have, over several centuries, provided the foundation for much of the economy of the western part of the county.

Available records indicate that from the veins and associated flat deposits of County Durham have been mined about 1.4 million tonnes of lead ore, about 1.5 million tonnes of iron ore, over 2 million tonnes of fluorspar, almost 1 million tonnes of barytes, over 0.25 million tonnes of witherite, and almost 1000 tonnes of zinc ore.

Lead and iron mining can be reliably traced back to Medieval times, and earlier working, perhaps even by the Romans is possible, though not proved. The heyday of lead mining came in the 19th century. The collapse in world lead prices in the closing years of the 19th century brought the end for all but a handful of mines, and in 1931 increasing production costs resulted in the closure of Boltsburn Mine, the county's last significant lead mine. Since then, apart from a little mining for lead at Coldberry, lead ore production in the county has been as a by-product of fluorspar mining.

Iron mining also reached its peak of production in Weardale in the 19th century with large quantities of ore being supplied to the ironworks at Tow Law, Consett, Spennymoor and further afield.

A small amount of zinc ore was mined in the Harwood valley, Teesdale in the early years of the 20th century and a modest tonnage was recovered from the Killhope mines in the 1950's.

County Durham was one of the world's first commercial sources of fluorspar when industrial demand for this former waste product of lead mining developed in the 1880's. Fluorspar mining to a small extent helped to mitigate the severe economic consequences of the collapse of lead mining in the closing years of the 19th century. For many years large tonnages of fluorspar were recovered from old spoil heaps, from backfilled waste in former lead mines, and from mines re-opened or developed specifically to work this mineral. Large quantities of Weardale fluorspar were exported to the USA in the early years of the 20th century. A resurgence of exploration and increased production in the 1970's and 80's was followed by a progressive decline in output as the world price of fluorspar fell to levels which rendered the Weardale mines uneconomic. Large scale mining for fluorspar ended in 1999 with the final closure of the combined Groverake-Frazer's Hush fluorspar mine in Rookhope.

Photo 47. Groverake Mine, Rookhope. Surface plant and buildings of County Durham's last fluorite mine.

Barytes was for long periods an important mineral in the economy of County Durham. Substantial deposits were worked at Cow Green, Teesdale and at Close House, Lunedale, the latter mine finally being abandoned late in the 1990's. Barytes was mined alongside coal from a number of rich veins in the Durham coalfield, notably at New Brancepeth and Ushaw Moor collieries. A large vein of witherite in the Coal Measures was mined at South Moor until 1958, making County Durham one of the world's very few sources of this unusual mineral.

At the time of writing, working for vein minerals in County Durham is restricted to Rogerley Mine at Frosterley, where a small fluorite-rich 'flat' is being mined for several months each year as a source of fine mineral specimens by a small partnership of California-based mineral dealers.

Future commercial interest

In common with many of the world's disused mineral mines, the end of mining in the North Pennines owes more to the economic vagaries of world markets than to the exhaustion of the deposits. The collapse in world lead prices precipitated the closure of all but a handful of lead mines towards the end of the 19th century, and by the mid 20th century even this small number of survivors had succumbed to global economics. The county's fluorspar mines suffered a similar fate in the closing years of the 20th century.

Good prospects exist for the discovery of substantial reserves of fluorspar, particularly within the E-W Quarter Point vein structures such as the Rookhope Red and Slitt veins. Any serious interest in commercial exploration depends on a significant rise in world prices. Similar considerations apply to possibilities for future working of lead or zinc ores, though within County Durham any future for the working of these is likely to be as by-products of fluorspar mining.

Renewed interest in barytes, witherite or iron ores within the county must be considered unlikely.

Environmental issues

Centuries of mining for vein minerals have left a widespread legacy of opencast and underground workings, spoil heaps, buildings and smelting sites. Whereas several of these features may be considered essential elements in the county's physical and cultural landscape, and in some cases are protected as scheduled Ancient Monuments, others may be viewed less sympathetically.

Opencast workings, dilapidated buildings, open shafts and adits may comprise obvious hazards. Underground workings eventually collapse and may create craters or 'crown holes' at the surface. Metal-rich spoil heaps or accumulations of mine tailings or smelting wastes may be sources, or potential sources, of contamination. Numerous adits, whose original funtions included mine drainage, may be discharging contaminated water. The contamination of Rookhope Burn (*see page 100*) remains unresolved.

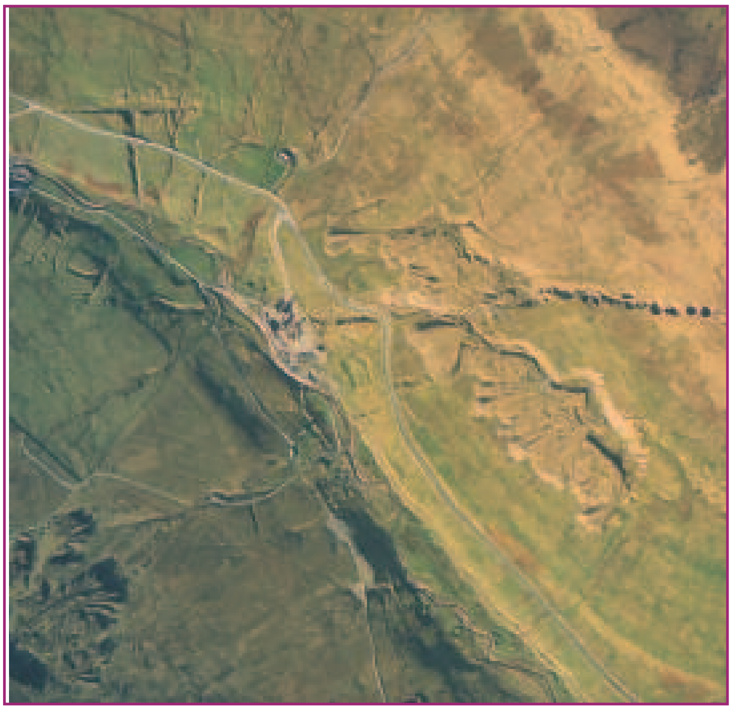


Photo 48. Aerial view of Groverake Mine, Rookhope. The course of Groverake vein is marked at the surface by a line of large crown holes.

Threats

Several of the surface exposures of mineral veins and associated flats within the county are reasonably robust. However, some of the finest surviving exposures of mineralisation lie within abandoned quarries. Particularly significant are the exposures of lead – fluorite mineralisation within Eastgate Quarry and similar vein mineralisation in Newlandside and Parson Byers quarries. Restoration or filling of these sites could destroy extremely instructive occurrences of important mineralisation.

In many places spoil heaps provide the only remaining evidence of the deposits once worked. They thus constitute important, in some instances unique, resources of geological and mineralogical material and information. Removal of spoil heaps, either as sources of low-grade aggregate, or as part of programmes of land reclamation, may pose very serious threats to these resources.

Important mineral occurrences in spoil heaps and exposures are locally threatened by uncontrolled collecting.

Wider significance

The mineral veins and associated deposits exhibit a number of features which give them national and international importance.

Similar orefields within the USA have given the term 'Mississippi Valley Type' to these orefields worldwide. The Northern Pennine orefield is one of the worlds finest, and best known, examples of such a 'Mississippi Valley Type' orefield.

Of particular importance is the very clear zonal arrangement of minerals within the orefield, and the significance of this in understanding the origins and evolution of the mineralisation, particularly the relationship with the concealed Weardale Granite. Concepts and theories developed here continue to be of importance in understanding similar orefields across the world.

Whereas many aspects of the mineralisation have clear parallels with broadly similar orefields elsewhere, the North Pennines exhibits several very distinctive or unique features.

The orefield is remarkable for the abundance of carbonates of iron, magnesium, manganese and calcium as the minerals dolomite, siderite and ankerite, which occur widely in veins and flats. These mineral assemblages still offer very considerable research potential, likely to shed important light on the origin of these, and similar, deposits.

The widespread abundance of barium carbonate minerals in the area's mineral deposits is a feature which makes the North Pennines unique in the world.

The veins and associated deposits of the North Pennines have long been a source of beautifully crystallised examples of many of the constituent minerals.

Selected references

British Geological Survey, 1992, 1996; Burgess and Holliday, 1979; Cann and Banks, 2001;Dunham, 1990; Dunham and Wilson, 1985; Dunham et al. 1965; Dunham et al. 2001Fairbairn, 2003; Forbes et al. 2003; Forster, 1809, 1883; Johnson, 1970, 1995; Johnson and Dunham, 1963, 2001; Mills and Hull, 1976; North Pennines Partnership, 2001; Say and Whitton, 1981; Sopwith, 1833; Wallace, 1861; Young, 1997, 2001, 2003.

Geological SSSIs

SSSI Name	GCR Name	Grid Reference
Close House Mine	Close House Mine	[NY 850 227]
Foster's Hush	Foster's Hush	[NY 859 204]
Old Moss lead Vein	Killhope Head	[NY 820 433]
Upper Teesdale	Lady's Rake Mine and Trial Shaft	[NY 803 344]
Upper Teesdale	Pikelaw Mines	[NY 902 314]
Upper Teesdale	Willyhole Mine	[NY 911 391]
West Rigg Open Cutting	West Rigg Open Cutting	[NY 911 391]

Durham County Geological Sites

Boltsburn Mine and Rookhope Borehole	[NY 937 428]
Cement Works Quarry, Eastgate, Weardale	[NY 935 360]
Chilton Quarry, Ferryhill	[NZ 300 314]
Closehouse Mine	[NY 84 22 – NY 85 22]
Coldberry Gutter	[NY 920 292]
Cow Green Mine	[NY 815 308]
Dirt Pit Mine	[NY 891 290]
Greenhurth Mine	[NY 795 320]
Greenlaws Mine	[NY 889 370]
Grove Rake Mine and Opencast	[NY 897 442]
Hunters Vein	[NY 860 204]
Killhope Lead Mining Museum	[NY 823 433]
Old Towns Quarry, Newton Aycliffe	[NZ 257 256]
Noah's Ark Quarry, Stanhope	[NY 985 409]
Raisby Railway Cutting	[NZ 345 350]
Scoberry Bridge – Dine Holm Scar, Teesdale	[NY 910 274]
Sedling Mine, Cowshill, Weardale	[NY 859 409 - NY 868 407]
Wynch Bridge	[NY 820 290]

QUATERNARY DEPOSITS

Quaternary deposits are sediments that were deposited during the Quaternary episode of earth history, between 2.5 million years ago and the present day. The Quaternary is divided into two periods: the Pleistocene Period dates from 2.5 million years ago till 11,500 years ago and the Holocene continues to the present day.

Quaternary deposits in Great Britain

At the start of the Quaternary, which is commonly referred to as the 'Ice Age', an episode of global cooling caused polar ice sheets to extend southwards to cover much of Great Britain and Northern Europe. During the Quaternary the climate oscillated between colder (glacial) and warmer (interglacial) stages. Study of sediments, landforms and fauna onshore and offshore have identified 14 to 17 stages of alternating cold **glacial** and warm **interglacial** conditions in Great Britain. The most recent glaciation ended around 11,500 years ago. The extensive ice sheets, which in places were over 1 km thick, resulted in erosion and modification of the existing landscape. The effects of persistent freeze-thaw action in ground which was often very deeply frozen, and the deposition of a variety of glacial sediments further modified this pre-existing landscape.

The deposits of the Holocene Period, reflect erosion and deposition in a varied succession of environments during much milder climatic conditions.

The distribution of Quaternary deposits varies depending on the processes active at the time and the pre-existing landscape. Figure 23 shows the maximum extent of the last regional glaciation in Great Britain and hence the areas that are wholly or partially covered by glacial deposits. Older, weathered and dissected glacial deposits occur as far south as London.

Figure 23. Maximum extent of ice in Great Britain during the Devensian glaciation

More recent, Holocene, fluvial deposits occur in almost all valleys or river courses and are still forming. These include a wide range of deposits including clays, silts, sands and gravels. Landslips occur in many areas and are not necessarily limited to steep slopes or hillsides. Peat deposits also developed during the Holocene after the glaciers retreated and occur both in local topographic lows in the deglaciated landscape and as extensive expanses of blanket bog over areas of high ground. Such peat deposits are particularly extensive in the Southern Uplands of Scotland, the Pennines and Dartmoor.

Quaternary deposits and their interpretation provide a wealth of information on the environments of the recent geological past. Information from glacial landforms and the nature and morphology of glacial deposits is essential to understanding these climatic conditions and may provide valuable insights into likely future environmental changes related to global warming.

The study of Holocene fluvial sediments allows interpretation of the evolution of rivers or streams, including extreme events such as flooding. In places, such deposits may also record the influence of human activities.

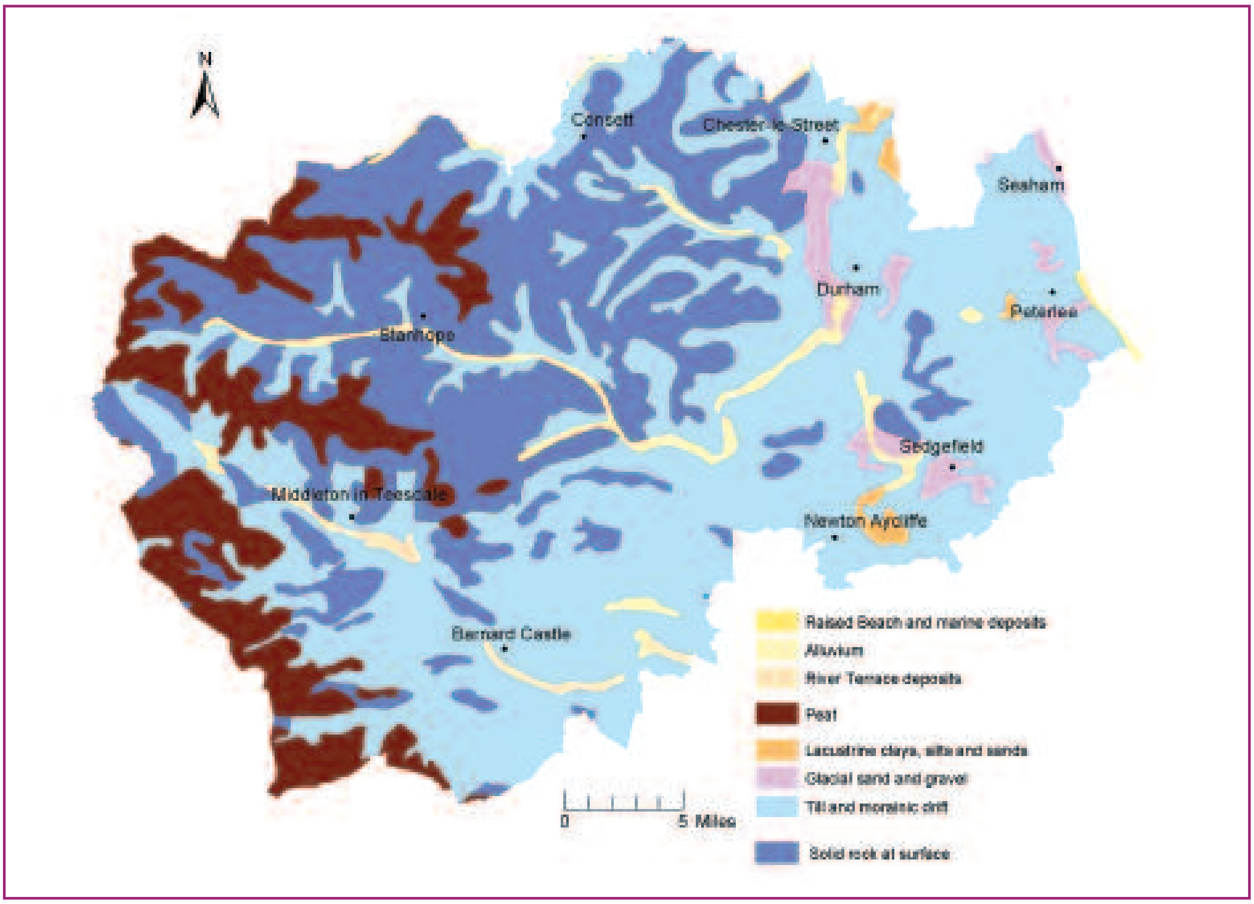


Figure 24. Distribution of Quaternary deposits in County Durham

Quaternary deposits in County Durham

Quaternary deposits are widespread over County Durham. They conceal the bedrock in many of the upland valleys and cover substantial areas of the lowland parts of the county (*see figure 24*). Detailed mapping of Quaternary deposits in County Durham is incomplete. Except for geological mapping under-taken within the past three to four decades, the extent of superficial deposits is significantly under-represented on Geological Survey maps, as older surveys paid most attention to delineating the bedrock.

In County Durham, as in much of Great Britain, the surviving deposits date mainly from the last, Devensian, cold stage, with only very limited evidence preserved of earlier cold and interglacial stages. However, the deposits found within the county are varied and complex reflecting the dynamic conditions during this period of time.

Glacial deposits

Fissure fills in the Magnesian Limestone coastal cliffs may represent the oldest deposits in the area, likely to have formed in the Lower and Middle Quaternary. The fissures contain a variety of boulders, fragments of rock and clay that have been forced in from above by later glaciations. Fossil material in some of the fissure fill from Blackhall Colliery and Warren House Gill includes shells, peat, tree trunks, insects, rodent teeth and the vertebra of an elephant resembling *Mammuthus meridionalis*. Some of the fissures contain exotic rocks similar to those within the later Scandinavian Drift.

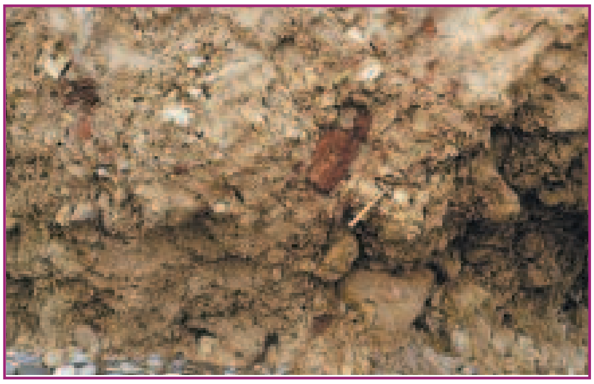


Photo 49. Shippersea Bay, Easington. Quaternary debris filling fissure in Magnesian Limestone.

Photo 50. Haugh Hill, Harwood, Teesdale. Till overlying striated pavement of Whin Sill dolerite.

Till (or boulder clay) usually consists of a heterogeneous mixture of grey silty clay with rock fragments ranging in size from gravel and pebbles to boulders: lenses of silt, sand and gravel may be present locally. Till may form drumlins or moraines (*see Landforms*). Till covers nearly all the bedrock in the eastern and central parts of the county. The deposits in the western area are discontinuous up to 615m above sea level. A common feature of several Northern Pennine valleys is the asymmetrical cover of till. Typically till cover is more or less continuous and comparatively deep on valley sides facing away from the direction of ice flow (known as the lee side). The opposite slopes are commonly free, or almost free, of till cover. Examples may be seen in parts of the Rookhope, Middlehope and Swinhope valleys in Weardale.

A variety of tills have been identified within the county, formed at different times within the Quaternary period:

Scandinavian drift – Warren House Till has been identified as a deposit that may have formed before the last glaciation. The deposits contain exclusively Scandinavian rocks save for some local Permian limestone. The ice mass from which this till was deposited originated in Norway, crossed the North Sea and covered the coastal parts of the county, but it is unlikely that the ice travelled further inland. This glacial deposit, the oldest in the area, is found in the base of buried valleys and topographic lows, the clearest exposures of which are found on the coast at such localities as Warren House Gill.

Lower tills and gravel containing North British rocks including Lake District and Scottish rocks were deposited by the British ice sheet after the Scandinavian ice sheet retreated. It is possible that there is a complete climatic cycle between the deposition of the Scandinavian and British Drift deposits.

The ***Upper till*** overlies both the Lower Till and the Scandinavian drift, the Easington Raised Beach and some sand and gravel deposits described below. The deposit is widespread and was deposited during the last glaciation.

Erratics are boulders or larger blocks of rock, most commonly within till, that have been transported by glaciers and deposited far from their original source. They therefore give clear evidence of the direction of ice flow. Within County Durham erratics of a variety of distinctive Lake District rock types may be found. As described above, the different tills present in the county contain boulders with a variety of origins. These provide evidence for successive ice sheets which originated in Scandinavia, Southern Scotland, the Lake District and within the Pennines. A common feature of erratic boulders, especially when freshly exposed from the surrounding till, is the striking scratches or striations, created by grinding against other boulders within and beneath the ice sheet. Good examples of erratic boulders include the 'Devil's Stones' in the public gardens in the centre of Crook.

Photo 51. Devil's Stones, Crook. Erratic boulders of volcanic rocks from the Lake District.

Glacial rafts may be considered as giant glacial erratics. Rafts are defined as bodies of sediment that have been transported by the ice, plucked from their original position and deposited elsewhere as the sediment freezes on to the base of the ice sheet. Several striking examples of large Dinantian Limestone erratics up to many metres across may be seen on Herdship Fell, Upper Teesdsale. Many large glacial rafts were revealed in opencast coal workings, notably in the Tow Law area, that have since been infilled. Rafts of peat incorporated into the till were exposed in a temporary road cutting at Hutton Henry. Borings for coal elsewhere in the north of the county have proved rafted masses of Coal Measures rocks within the drift. In some cases opencast coal workings have been entirely in such rafts.

Photo 52. Herdship Fell, Teesdale. Large erratic mass of Dinantian limestone.

Sand and gravel deposits are variable, occurring in a number of different settings within the Quaternary deposits of County Durham. In some areas these deposits have been identified as glaciofluvial deposits (described below) and are recorded as such on the Geological Survey maps. The mechanism of deposition of other sand and gravel deposits has not been differentiated on these maps. In parts of the county a tripartite division in the Devensian (last glacial) sediments has been recognised. This consists of the Lower and Upper tills, separated by an intervening body of sand and gravel referred to as the Middle or Ryhope Sands. These deposits may have been deposited by meltwaters from the retreat of the western ice back to the Lake District and Southern Uplands. Other bodies of sand and gravel include more recent deposits overlying the upper till and locally a group of basal sands and gravels.

Glaciofluvial deposits are bodies of sand and gravel that are the products of meltwater discharging from ice sheets and formed in a similar way to modern braided streams. Glaciofluvial sand and gravel deposits occur in the valleys and the eastern part of the county. During deglaciation, following the last glacial maximum, the ice thinned and it began to follow the influence of the underlying relief, becoming confined to the lower parts of the valleys. It is in these valleys that extensive sands and gravels were deposited.

Glaciolacustrine deposits usually consist of sands, silts and clays deposited in a lake adjacent to a glacier. In Durham during deglaciation following the last glacial maximum, large quantities of meltwater formed lakes. Water flowing to the east was blocked by the North Sea ice lobe creating the large glacial Lake Wear. Within this was deposited a widespread succession of laminated silty clays, fine-grained sands, stony clays and some basal gravels, known as the **Tyne-Wear complex**. Although this sequence is not distinguished on most BGS maps, its constituent lithologies are recorded as Laminated Clay or Glacial Sand and Gravel. The complex formed at the same time as the Middle or Ryhope Sands and may be found in the sequence between the Upper and Lower tills.

Photo 53. Cauldron Snout, Teesdale. The pre-glacial channel of the River Tees, now plugged with till, can be seen in the river bank.

Pelaw Clay is a thin heterogeneous layer of clay, overlying the clays deposited by glacial lakes and may have resulted from periglacial mass flow processes.

Buried valleys within County Durham are the pre-glacial valleys of the modern rivers which are now choked by, and concealed beneath, substantial thicknesses of till and other glacial deposits. The county has striking examples of such buried valleys clearly visible at Cauldron Snout, where the till-choked pre-glacial valley of the River Tees lies a few tens of metres west of the present river course, the valleys on the coast

Photo 54. Shippersea Bay, Easington.The Easington Raised Beach.

at Warren House Gill and Hawthorne Dene, the buried valley of the river Wear to the north of Chester-Le-Street and the diversion of the Wear through Sunderland.

Raised marine deposits are fossil beach deposits found elevated above the modern sea level. Easington Raised Beach is a fine example of a raised beach. The partly cemented gravels are over 30m above the modern sea level and the deposit contains marine shells as well as pebbles bored by marine molluscs and worms.

Peat deposits include both extensive blanket bogs, generally in the uplands in the western part of the county, and basin peats. These latter deposits occupy hollows or depressions in glacial drift or ice-eroded bedrock and are found in isolated patches in the central and eastern parts of the county. Generally blanket peat is up to two metres thick whereas basin peat may locally be much thicker.

Periglacial deposits

Under ***periglacial*** conditions the modification of existing deposits and rockhead occurs by various processes. Those affecting the deposits at the surface include solifluction and freeze-thaw action generating deposits of head and scree.

Head is the term used to describe spreads of poorly sorted angular rock debris mantling hillslopes and deposited by gelifluction. This process is the flow of water-saturated bodies of debris over frozen ground and only occurs in the uppermost 3 metres of superficial deposits. Such material is almost certainly present over many hillsides within the county, though it has not been separately delineated on published geological maps of the county.

Scree, also called talus, consists of accumulations of broken rock fragments which have been moved by gravity down steep slopes. Examples occur near the foot of the Whin Sill Crags on Cronkley Fell.

Permafrost conditions

Modification of the subsurface structure of deposits and sediments occurs in zones of permafrost. This defines areas where ground is permanently frozen for a substantial period of time and the penetration of ground ice is deep. Two features that formed under these conditions in County Durham have been recognised:

Involution is the distortion and twisting of unconsolidated sediments. This occurs due to changes in density and pressure associated with the presence of a frozen layer overlying unfrozen sediments. Such movement is also referred to as **cryoturbation**. Distorted deposits demonstrating the process of involution are exposed in sand and gravel deposits found in the coastal cliffs near Whitburn.

Ice-wedge casts are features formed as the result of cracking of the ground due to contraction during periods of extreme cold, followed by water penetration and freezing within the crack. Upon melting the ice is replaced by material falling in from the top and sides so that a cast or pseudomorph of the original ice wedge is preserved. Ice wedge casts have been noted in some localities such as in Coal Measures mudstone at an opencast site near Leamside and in gravel NE of Sherburn.

Holocene deposits

Lacustrine deposits are sediments, usually consisting of laminated silty clays and fine-grained sands, deposited in former lakes. Extensive areas of such deposits are found in the southeast of the county forming flat areas of ground. Areas of peat may be associated with such areas. These distinct landscapes are referred to as 'carrs', excellent examples of which can be seen in the area to the south of Bradbury [NZ 312 254].

Holocene fluvial deposits include a variety of alluvial sediments, ranging from silts and clays to coarse sands and gravels, which form flat spreads adjoining streams and rivers. Such deposits may accumulate as flat sheets on river or stream floodplains. Fluvial deposits occur extensively in close proximity to current river and stream channels and many abandoned channels.

River terraces deposits are dissected remnants of former floodplain deposits lying above the modern flood level. They represent accumulations of alluvial material deposited during earlier phases of river development, and record changes in base level and may reflect climatic conditions during Late-glacial and Holocene times.

Beach deposits comprise accumulations of sand and shingle exposed between the high and low water marks. In addition to boulders and pebbles of Magnesian Limestone, a high proportion of the naturally occurring beach material on the Durham coast appears to have been derived from the Quaternary deposits eroded from the cliffs. A variety of glacially transported rock types can be seen in most accumulations of beach shingle. Most prominent are boulders of Carboniferous limestones and sandstones, with smaller quantities of Whin Sill dolerite, some Cheviot volcanic rocks and rocks derived from southern Scotland and the Lake District.

Many years of dumping of colliery spoil particularly from collieries in the Dawdon and Easington area led to huge and disfiguring accumulations of Coal Measures shale, sandstone, pyrite and some coal on the Durham beaches. Long-shore drift spread much of this material southwards along the coast. Through the recent 'Turning the Tide' project, Durham County Council have removed much of this contamination and many of the county's beaches are now approaching their original composition. Concentrations of colliery spoil remain locally, notably in the Dawdon and Hawthorn areas where the beach deposits locally contain high concentrations of pyrite.

Photo 55. Hawthorn Hive. Pyrite-rich sand derived from colliery spoil.

Storm beach deposits are accumulations of beach material built up by storms and high tides well above normal high tide level. Substantial deposits of colliery spoil at Dawdon Blast Beach and at Hawthorn Hive are, in effect, storm beach deposits, albeit composed of tipped material.

Blown sand occurs as coastal dunes in the extreme south of the county around Crimdon. The largest patches of Blown Sand are up to 2 metres thick.

Influence on the landscape

Apart from modifications due to human intervention, virtually the entire present day landscape of County Durham is the result of erosion and deposition during Quaternary times. The most important of these processes date from the major glacial episodes though it is important to appreciate that, in common with all natural landscapes, that of County Durham is dynamic and still evolving in response to natural processes.

In parts of the Durham Dales, the prominent bench features associated with the cyclical deposits of the Carboniferous limestones, sandstones and shales, locally contrast dramatically with much more subdued rounded till-mantled slopes. The characteristic 'half egg' shaped hills, known as drumlins, are characteristic of till in parts of Weardale, Teesdale, around Easington and the City of Durham.

In the lowlands, Quaternary deposits mantle the pre-glacial bedrock topography. As a result, variation in the relief of the surface may be less than that of the underlying bedrock. The bedrock surface may locally be below present day sea level. Thus some coastal areas are only above sea level due to the presence of glacial drift.

Glacial sand and gravel deposits form features such as kame terraces (*see Landforms*).

Lacustrine deposits form extensive areas of open, largely flat 'carrs' such as Bradbury, Preston and Mordon Carrs.

Holocene fluvial deposits form flat ground adjoining rivers and streams.

Influence on biodiversity

Where Quaternary deposits mantle the solid rock, the soils are significantly influenced by the composition of the 'drift' rather than the bedrock.

These deposits also influence infiltration of water and the movement of water as groundwater. Sand and gravel deposits have characteristics different from clayey tills creating areas of well- or poorly-drained ground which may be reflected by variations in vegetation.

Extensive spreads of comparatively impervious till may have encouraged the development of blanket peat.

River terraces and alluvial deposits support a characteristic flora. Shingles are well drained and such areas may be subject to rapid erosion and flooding. Some plant communities are reliant on unstable, or rapidly eroding, conditions thereby eliminating or limiting competition from more vigorous species.

Photo 56. Durham Gravel Pit. Glacial sands and gravels. Photographed 1965.

Some fluvial deposits in the west of the county, that contain high concentrations of heavy metals, support specialised metallophyte plant communities including Alpine pennycress (*Thlaspi alpestre*) and Spring sandwort (*Minuartia verna*) (*see Mineral Veins*). Metalliferous mining not only influenced the metal content of sediment and water, but also resulted in modification to the morphology of many rivers and streams.

Flooded abandoned sand and gravel workings are prominent in parts of the Wear valley, notably at Low Barns Nature Reserve, where they provide important habitats for a wide range of wildlife species, including migratory and wading birds.

Economic use

Glacial sand and gravel deposits have been worked in several parts of the county. Glaciolacustrine deposits have been worked in the past as a source of brick clay. Hill peat has locally been worked as a fuel, notably for lead smelting. In addition erratic boulders and clearance stones, derived from glacial deposits, have been employed in drystone walls and vernacular architecture (*see Built Environment*).

In the 18th and 19th centuries glacial laminated clays were dug for the manufacture of bricks, tiles and pipes in many large pits between Durham and Finchale Priory, between Thornley and Shotton and between Wellfield and Station Town. Bricks and tiles were also formerly manufactured from till for example southeast of Tursdale Colliery and between Nunstainton East and Sedgefield.

Wider impact

Several sites exhibiting sections through glacial deposits within the county are designated as GCR sites for their importance in interpreting glacial periods and processes, recognising interglacial periods and the relationship between these for the history of the northeast coast.

Selected references

Boulton et al. 1985; Brigland et al. 1999; Burgess and Holliday, 1979; Gregory, 1997; Gregory et al. 2002; Huddart and Glasser, 2002; Johnson, 1970, 1995; Johnson and Dunham, 1963; Mills and Holliday, 1998; Mills and Hull, 1976; Pounder, 1989; Smith, 1994; Smith and Francis, 1967; Taylor et al. 1971.

Geological SSSIs

A number of additional SSSIs in Quaternary deposits are listed under the landforms section.

SSSI Name	GCR Name	Grid Reference	GCR Block
Durham Coast	Shippersea Bay, Easington	[NY 443 453]	Quaternary of North East England
Durham Coast	Warren House Gill	[NY 436 426]	Quaternary of North East England
Durham Coast	Marsden Bay	[NZ 400 650]	Coastal Geomorphology of England
Upper Teesdale	Upper Teesdale, Red Sike Moss	[NY 819 290]	Pollen stratigraphy of England

Durham County Geological Sites

Knotty Hill (and Hoppyland Kames)	[NZ 084 319 – NZ 102 321]
Castle Eden Dene	[NZ 422 397 - NZ 440 400]
Easington Raised Beach	[NZ 443 453]
Sacriston Subglacial Channels	[NZ 23 49] and surrounding area
Part of Sheraton Kame moraine	[NZ 440 367] (A19 road cutting account in literature)

KARST FEATURES

Karst features are those formed over soluble rocks such as limestone, dolomite or gypsum, and characterised by sinkholes, caves and underground drainage. The term derives from the massive limestone country of Yugoslavia where many of the landforms have been produced by solution.

Karst features in Great Britain

Karst features in Great Britain include limestone pavements, cave systems, stalactitic and stalagmitic deposits, tufa and calcareous spring deposits, sink holes or dolines, and dry valleys.

In Great Britain most karst features are associated with limestone outcrops. Excellent karst features are therefore to be found in areas of extensive limestone outcrops. Notable examples include the outcrops of Carboniferous limestones in North and South Wales, the Mendips, Derbyshire, South Cumbria and the Yorkshire Dales. Good karst features are developed on comparatively small outcrops of Cambrian limestones in North West Scotland and the Isle of Skye.

Gypsum is a much more soluble rock than limestone. Indeed, it is so soluble that such beds have normally suffered extensive dissolution near to the surface and natural outcrops are rare in Great Britain. Most beds of gypsum within Britain occur within rocks of Permo-Triassic age. Gypsum karst features, mostly caves and surface collapses above them, include those associated with the outcrops of these rocks at Ripon in North Yorkshire. Collapse features associated with gypsum dissolution are known in the Darlington area.

Karst features give important evidence of the processes involved in the active dissolution of soluble rocks in the comparatively recent geological past. Caves systems may contain sediments which yield evidence of their former occupation by a variety of animals, including early man.

Karst features in County Durham

The following karst features, all associated with limestones, are present within County Durham:

- ***Sink holes or dolines***
- ***Springs***
- ***Caves***
- ***Dry valleys***
- ***Limestone pavement***
- ***Tufa deposits***

The majority of karst features within County Durham are associated with the Carboniferous limestones in the west of the county though a smaller number are present in the east of the county on the outcrop of the Permian Magnesian Limestone.

Karst features associated with Carboniferous limestones:

Although limestones are important components of the succession of Carboniferous rocks within County Durham they are mostly comparatively thin and separated from one another by substantial thicknesses of insoluble rocks such as shales and sandstones. Karst features are therefore less prominent within the county, and generally much less well developed, than in the nearby limestone country of South Cumbria and the Yorkshire Dales.

However, the outcrops of many of the Carboniferous limestones in the county are associated with lines of **sink holes** or **dolines** which, in areas with a moderate covering of superficial deposits, may provide valuable clues to the presence of limestone. Particularly good examples may be seen marking the top of the Great Limestone at numerous places in parts of Weardale and Teesdale.

Photo 57. Aerial photograph of sink holes into Great Limestone, Teesdale.

Springs, or lines of springs, occur close to the base of many Carboniferous limestone outcrops. During periods of prolonged dry weather Harehope Burn dissappears underground through enlarged joints in the Great Limestone. The stream emerges at the surface several metres downstream as a prominent spring. The county does not exhibit the conspicuous **dry valleys** which are such characteristic features of some limestone areas.

The few **cave** systems known in the county are confined to the Carboniferous limestones and are generally of limited size and do not match the spectacular systems of the Yorkshire Dales. The area's best known caves are those at Fairy Holes and Jacob's Pot, in Weardale, and the Teesdale, or Moking Hurth, Cave near Langdon Beck. The Teesdale Cave is known to have yielded mammalian bones.

Photo 58. Jacob's Pot, Harehope Quarry, cave in Great Limestone.

County Durham also contains Britain's finest example of a natural limestone bridge, in the Great Limestone at God's Bridge near Bowes.

Photo 59. God's Bridge. A natural arch in Great Limestone over the River Greta.

The county contains no good examples of **limestone pavement** to match those in adjoining areas of Cumbria and North Yorkshire. However, outcrops of Smiddy Limestone and metamorphosed Melmerby Scar Limestone ('Sugar Limestone') on Widdybank Fell, Teesdale, where free of soil cover, locally exhibit widening of joints reminiscent of limestone pavement.

Small areas of **tufa** are forming adjacent to a lime-rich spring in Greenfoot Quarry, Stanhope.

Karst features associated with Permian limestones:

Karst features are much less common associated with the Magnesian Limestone of eastern County Durham.

Whereas open fissures resembling sink holes, or dolines, are known in parts of the Magnesian Limestone outcrop, especially where superficial cover is thin, these appear to be related to subsidence over areas of former underground coal mining. Recent investigations suggest that they mainly result from continued, or renewed, dilation of joints and collapse of joint-filling materials. Substantial open fissures in the Magnesian Limestone in Hawthorn Dene may be true dolines.

Solution features are rare within the Permian limestones, though some evidence of slight solution-widening of joints and thin coatings of calcite 'flowstone' can be seen in several quarries. Substantial parts of the Magnesian Limestone comprise dolomite or dolomitic limestone and are thus much less soluble than pure limestone.

The denes of the Durham coast comprise deep canyon-like valleys cut through the cover of superficial deposits into the underlying Magnesian Limestone. Although not true karst features, in some instances, e.g. at Castle Eden Dene, the valley is in part a dry valley with drainage underground for substantial periods of most years.

Tufa deposits are associated with springs at two localities in the Trimdon and Shotton areas.

Influence on the landscape

Features such as sink holes and dry valleys are small, but conspicuous and integral, parts of the area's landscape.

The denes on the outcrop of the Magnesian Limestone are well-known and important elements in the landscape of the east of the county.

The small number of caves are significant, though concealed, landscape features.

Influence on biodiversity

Caves provide important specialised wildlife habitats. These include important bat roosts. The Fairy Holes Cave is said to support a unique fish population.

Limestone grasslands are important plant habitats.

Lime-rich spring water locally has a strong influence on plant communities.

Economic use

Karst features appear to have been of little economic use within the county.

Environmental issues

Although extensive cave systems are rare within the county, sink holes and solution-widened joints are common within the Dinantian and Namurian limestones. Due caution should therefore be applied when planning and undertaking of any form of groundworks or land-filling on, or in the vicinity of, such limestone outcrops.

Solution features are not known to be widespread within the county's Permian limestones. However, joints and fractures in the vicinicty of known faults may locally be dilated and potentially unstable in areas undermined by abandoned coal workings. Particular attention should be paid to the possible presence of such fissuring when planning or undertaking groundworks in such areas.

Joints and fissures in limestone, particularly where enlarged by dissolution, may provide ready pathways for contaminants, especially in quarries and landfill sites.

Threats

Portions of the Fairy Holes Cave system have been removed during limestone extraction at Eastgate Quarry. The quarry has now closed and the cave entrance is secured.

Filling of sink holes or dolines with farm, or other waste may locally threaten to damage or obliterate examples of these features, though this is not currently seen as a serious threat.

Wider importance

The Fairy Holes Cave, Weardale, is scheduled as an SSSI as "…the longest known stream passage in the Yoredale limestone of the North Pennine Dales…it is significant as the best developed example of its type."

The surface fissures associated with the outcrop of the Magnesian Limestone, though not necessarily exclusively karst features, have been the subject of research relevant to geological processes which affect Magnesian Limestone elsewhere in Great Britain.

Geological SSSIs

SSSI and GCR Name	Grid Reference	GCR Block
Fairy Holes Cave	[NY 936 356]	Caves
God's Bridge	[NY 957 126]	Karst

Durham County Geological Sites

There are currently no karst features designated as Durham County Geological Sites.

Selected references

Johnson and Dunham, 1963; Pounder, 1989; Waltham et al., 1997.

Photo 60. Entrance to Fairy Holes Cave in Great Limestone, Eastgate Quarry, Weardale.

The mammalian fauna recovered from the Teesdale Cave is an important example of a Quaternary fauna.

God's Bridge is scheduled as an SSSI as Britain's finest example of a natural limestone bridge.

LANDFORMS

Landforms make up the landscape we see today. Geomorphology is the scientific study of landforms. Landforms provide clear evidence of the processes of erosion and deposition which have shaped the land over geological time. Most landforms are the result of processes which operated within the Quaternary period.

Interpretation of landforms and Quaternary sediments can thus provide evidence of environmental conditions and climatic oscillations in the recent geological past. This includes evidence for the spread of ice sheets in Great Britain. Such information may provide valuable insights into likely future changes as part of studies of global warming.

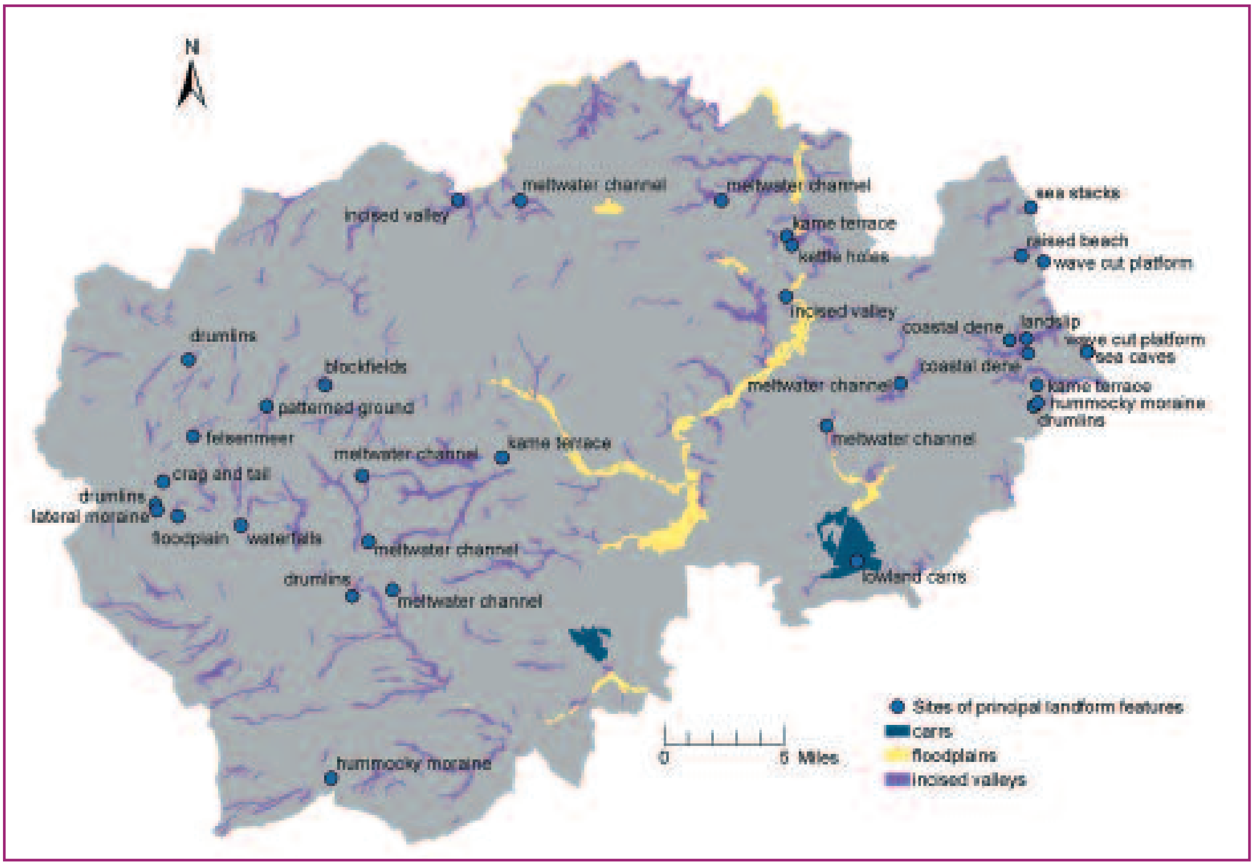


Figure 25. Distribution of major landforms in County Durham

Landforms in County Durham

The landforms within the county can be divided into several categories based on the processes that formed them.

GLACIAL LANDFORMS

Landforms produced during stages of the Quaternary when ice sheets covered parts of northern England may be the result of various processes:

Glacial erosion

This is the removal of rock and superficial

Photo 61. Hown's Gill, Consett. A large glacial drainage channel.

material due to the movement of ice. Glacial erosion coupled with the deposition of glacial sediments had an influence on the general landscape and affected the landforms present today. Although Northern England is known to have been covered by ice during several glacial episodes during the Quaternary, the erosion features seen in today's landscape almost invariably result from the most recent, Devensian, glaciation.

Glacial deposition

This involves the deposition of a varied range of sediments, mainly debris transported by ice sheets and glaciers. Deposition may have occurred beneath an ice sheet, at its margins or at the end of a glacier, or as a result of water released from the ice as it melted.

Erosion features:

Glaciated valleys

These are valleys whose form has been significantly modified by the erosive power of moving ice. Whereas glaciers do not normally create valleys, they are known to be capable of causing substantial changes to the form of an existing valley. These effects include the truncation of spurs and the creation of a characteristic 'u-shaped' profile. Although all the major valleys within the county have been modified by glacial action, the area lacks the spectacular characteristics of the glaciated valleys of the nearby Lake District and the Pennine escarpment.

County Durham includes a number of valleys, which were modified by glacial action, but are today concealed beneath thick deposits of glacial and post-glacial superficial deposits (*see Quaternary Deposits*).

Glacial drainage channels

Also known as meltwater channels, these are channels of variable scale, usually steep-sided and flat-floored, cut by large volumes of water during the melting of ice sheets and glaciers. They may be unrelated to the present drainage pattern. Good examples may be seen at several places within the county such as the channels near Eggleston, Ferryhill Gap, Kelloe, and at Hown's Gill near Consett.

Denes

The Durham Denes are conspicuous features of the landscape in the eastern part of the county. These west-east orientated steep-sided coastal valleys are incised through the cover of Quaternary Deposits into the Magnesian Limestone. The 'denes' are in part glacial meltwater channels, cut rapidly by streams flowing to the North Sea at the end of the Devensian glaciation. The distinct morphology of these channels in this coastal area is due to the rapidity of the erosion.

Asymmetric valley profiles

A feature of several North Pennine valleys is their markedly asymmetric profile. This reflects strong glacial erosion, or scouring, on one side of the valley, with deposition of substantial spreads of glacial debris on the opposite side. Such valleys thus exhibit a stepped profile on the scoured side, with a much smoother profile on the side covered by glacial debris. Although this feature can be seen in some valleys in the western part of the county, better examples are seen further west around Alston.

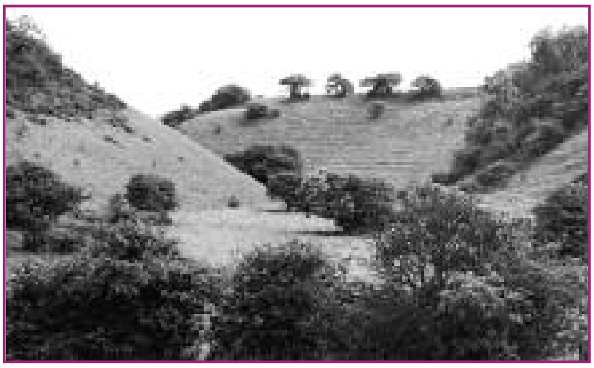


Photo 62. Kelloe meltwater channel, Kelloe. Photographed 1960.

Depositional features:

Drumlins

These are ovoid mounds of glacial debris, mainly till, which were deposited beneath an ice sheet and smoothed into a streamlined shape by the passage of the over-riding ice. The term drumlin is derived from druim, a gaelic term for a mound or rounded hill. Typical drumlins exhibit an extremely distinctive 'half egg' shape. They commonly occur in large groups. The term 'basket of eggs' topography is sometimes applied to areas of well-developed drumlins. Good examples of drumlins are present in Teesdale and Weardale.

Photo 63. Harwood, Teesdale. The River Tees cuts through a large drumlin.

Crag and tail

This refers to features formed where a resistant mass of rock has withstood the passage of an ice sheet, thereby protecting an elongated ridge of less resistant rock or debris on the leeward side. Several small knolls, or 'crags', of Whin Sill dolerite are associated with such elongated 'tails' of till in Teesdale.

Moraine

This is a term which was originally used to define the ridges of rock debris that were found around Alpine glaciers. This definition has since been expanded to include the rock debris deposit as well as the landform and is described as **morainic drift** on BGS maps. Several types of moraine may be recognised. These reflect both their form and the process by which they formed. In the county some landforms have been interpreted as **lateral moraines**, such as those at the foot of Cronkley Scar in Teesdale, formed as accumulations of debris at the margin of a valley glacier. **Hummocky moraine** is also present. This is caused by thinning of the ice, possibly during melting of the ice sheet and results in a strongly undulating surface with steep slopes and deep depressions. An area of hummocky moraine is identified between Easington, Elwick and Hart on the east coast of the county.

Kames

These are conical hills, usually composed of stratified sands and gravels, formed from a crevasse filling in an ice sheet, or as accumulations of such materials on the surface of an ice sheet. Undulating kame terraces are found in the Wear lowlands around Durham City.

Kettle Holes

These are often found in the surfaces of kames or moraines. These closed depressions result from the melting of a body of ice that was included within the glacial deposit. They are typically filled with water forming small lakes. In places in the east of the county some kettle holes have been filled with peat.

Periglacial features

These are formed in environments characterised by freeze-thaw action in areas bordering ice sheets.

Blockfields or Felsenmeer

These are accumulations of angular frost-shattered blocks, usually adjoining rock exposures, examples of which can be seen on the ground around Snowhope and Bollihope Carrs, in Weardale.

Stone stripes and circles are types of **patterned ground**. They comprise linear or circular accumulations of stone fragments on the ground surface, formed as a result of disturbance of the ground by repeated freezing and thawing.

POST-GLACIAL LANDFORMS

These are landforms developed after the retreat of the ice sheets formed mainly during the Holocene period of Earth History. These landforms have also developed through processes of erosion and deposition but are unrelated to bodies of ice and associated meltwaters and are similar to the processes operating today.

Incised valleys

These are river valleys cut deep into the surrounding landscape due to accelerated down-cutting resulting from a lowering of sea level, or an increased volume of drainage during immediately post-glacial times. County Durham includes one of Great Britain's best known and most spectacular examples of an incised meander. The Durham meander on the River Wear is a 30 metre deep incised gorge cut into Coal Measures strata. The present drainage course is very different from the preglacial as the topography was buried and modified by the deposition of substantial thicknesses of glacial sediments, mainly till. The meandering course became fixed when incised into the Coal Measures rocks.

Photo 64. Cronkley Fell, Teesdale. Morainic deposits mantle the lower slopes.

Photo 65. The incised meander of the River Wear Durham City.

The 'peninsula' at Durham, enclosed by the meander provided a naturally defensive position for the Castle and an imposing site for the Cathedral, a World Heritage Site.

Very similar deeply incised meanders are present in the Derwent valley near Castleside.

Landslips

These are masses of rock or earth which have moved downhill as a result of the failure of those materials. They may result from the physical properties of the failed materials, or the geological conditions of their occurrence. A great variety of landslip types are recognised, reflecting the nature of the slipped material and the processes which caused the slipping. Small to medium sized landslips are common on valley sides throughout the county, though they may not have been mapped. Several landslips are prominent in the upper slopes of Blunts Dene, Castle Eden.

Floodplains

The part of the river valley that is periodically flooded and built up from sediment deposited by the river both during a flood and when the channel migrates laterally is known as the floodplain. Alluvial deposits of this sort may comprise sediment from coarse gravel to clay grade.

River Terraces

These are part of the river valley that stands above the level of the present floodplain. Terraces develop due to a fall in the sea level, uplift of the land or a change in climate. River terraces are typically composed of sediments comparable to those in alluvial floodplains.

Solifluxion terraces

These are small terraces found on hillsides, formed by downhill movement of soil and superficial materials as a result of either seasonal freezing and thawing, or permafrost conditions. They may be difficult to distinguish from **gelifluxion terraces**.

COASTAL LANDFORMS

In addition to numerous important exposures of Permian rocks and Quaternary deposits, the Durham coast includes a number of characteristic coastal landforms.

Sea cliffs

Sea cliffs extend almost continuously along the coastline of the county. Typically the cliff profile reflects the nature of the geological deposits exposed. The 'solid' limestones of the Magnesian Limestone generally stand as vertical or near vertical cliffs. Overlying this, a more gently inclined profile marks the exposure of a variety of Quaternary deposits, mainly till and sands and gravels. Variable erosion along cliff sections has produced a series of bays and headlands that characterize most of the Durham coastline.

It has been estimated that until the beginning of the 20th century parts of the Durham coast were eroding at an average rates of between 2 and 3 metres per year. Progressive accumulation of large volumes of colliery waste, dumped onto the

Photo 66. The Durham Coast at Easington.

beaches, resulted in a marked reduction in this rate of coastal retreat. With the ending of tipping, and the clearing of much of the accumulated spoil from sections of the coast, erosion rates of between 0.3 to 0.6 metres per year have been predicted.

Sea stacks

These are residual masses of rather more resistant limestone created by the retreat of the cliff line.

Photo 67. 'The Chair', Blackhall Rocks, a natural arch in Magnesian Limestone, immediately prior to demolition for safety reasons in 2004.

Good examples may be seen in the Seaham and Horden areas.

Sea caves

Caves of varying sizes are present within the Magnesian Limestone cliffs at many places along the coast. The Magnesian Limestone is locally extremely variable in its resistance to erosion. Caves are readily developed by wave action where the limestone is highly fractured by collapse brecciation, or adjacent to joints.

Natural arches

These typically develop by the progressive collapse of caves, forming a natural bridge or arch.

Wave cut platforms

These are more or less flat areas of bare rock cut by marine erosion at beach level. Examples include the expanses of Magnesian Limestone exposed on the beach between Hawthorn Hive and Horden Dene, and near Blackhall Rocks.

Beach deposits and Storm beach deposits

(*see Quaternary Deposits*)

Wider importance

The landforms of the county contribute important evidence to the understanding of the

Quaternary evolution and geomorphology of Northern England. Study of the morphology and sediments of various landforms may allow the glacial history, including the environmental conditions, climatic oscillations and movement of ice sheets, to be understood.

The incised meander of the River Wear gorge at Durham, which provides the imposing site for the Cathedral and Castle, is well-known and powerful images of this site are recognised worldwide.

Threats

Natural weathering and erosion inevitably modify and ultimately destroy many landforms. Coastal erosion is particularly potent. Deterioration of some landforms, particularly coastal cliffs and sea stacks, may impact upon public safety, and may necessitate remedial action. Advanced erosion of the arch, known locally as 'The Chair', at Blackhall Rocks resulted in the feature becoming unsafe. It was therefore demolished in February 2004.

Selected references

Boulton et al. 1985; Brigland et al. 1999; Burgess and Holliday, 1979; Forbes et al. 2003; Gregory, 1997; Gregory et al. 2002; Huddart and Glasser, 2002; Johnson, 1970, 1995; Johnson and Dunham, 1963; Mills and Holliday, 1998; Mills and Hull, 1976; Pounder, 1989; Scrutton, 1995;Smith, 1994; Smith and Francis, 1967; Taylor et al. 1971.

Geological SSSIs

In GCR Block "Quaternary of North-East England"

SSSI Name	GCR Name	Grid Reference
Durham Coast	Shippersea Bay Easington	[NZ 443 453]

There are a number of large SSSI and NNR areas, such as Moorhouse National Nature Reserve, within which numerous geomorphological features (landforms) can be found. These features benefit from a degree of protection associated with the SSSI but specific site protection is not for the landform.

Durham County Geological Sites

Bollihope and Snowhope Carrs	[NY 966 367 – NY 945 355]
Castle Eden Dene	[NZ 422 397 – NZ 440 400]
Ferryhill Gap	[NZ 30 34 – NZ 30 32]
Folly House Glacial Drainage channels, Eggleston	[NZ 011231 – NZ 027236]
Hesleden Dene and downstream continuation	[NZ 434 388 – NZ 469 370]
Holwick Drumlins, Romaldkirk	[NY 984 227]
Knotty Hills and Hoppyland Kames	[NZ 084 319 – NZ 102 321]
Sacriston Subglacial Channels	[NZ 23 49, NZ 27 49, NZ 27 45, NZ 23 45]
Scoberry Bridge to Dine Holm Scar	[NY 910 274 – NY 866 282]
Sharnberry Meltwater Channel	[NY 9907 3070]
Sheraton Drumlins	[NZ 438 353]
Part of Sheraton Kame moraine	[NZ 440 367]
St Johns Chapel Drumlins	[NY 875 384, NY 877 384, NY 879 384]
Thornley-Kelloe	[NZ 349 368 – NZ 304 383]
Wear River Gorge	[NZ 273 426 – NZ 276 426]

SOILS

An area's geological deposits provide the main source of inorganic ingredients for its soils. As the character of these soils is a major factor in determining the nature of the vegetation, there is thus a clear link between geodiversity and biodiversity. It has therefore been possible, in previous sections, to make a number of very broad general observations on the role of geology in influencing the area's biodiversity. However, soil formation (pedogenesis) also depends upon other factors such as climate, weathering processes, vegetation, input of organic matter, groundwater move-ment, complex chemical reactions and even human intervention including agricultural practices. Therefore, whereas over substantial parts of the county the character and properties of soils may closely reflect the underlying geology, in other places the link may be much less clear.

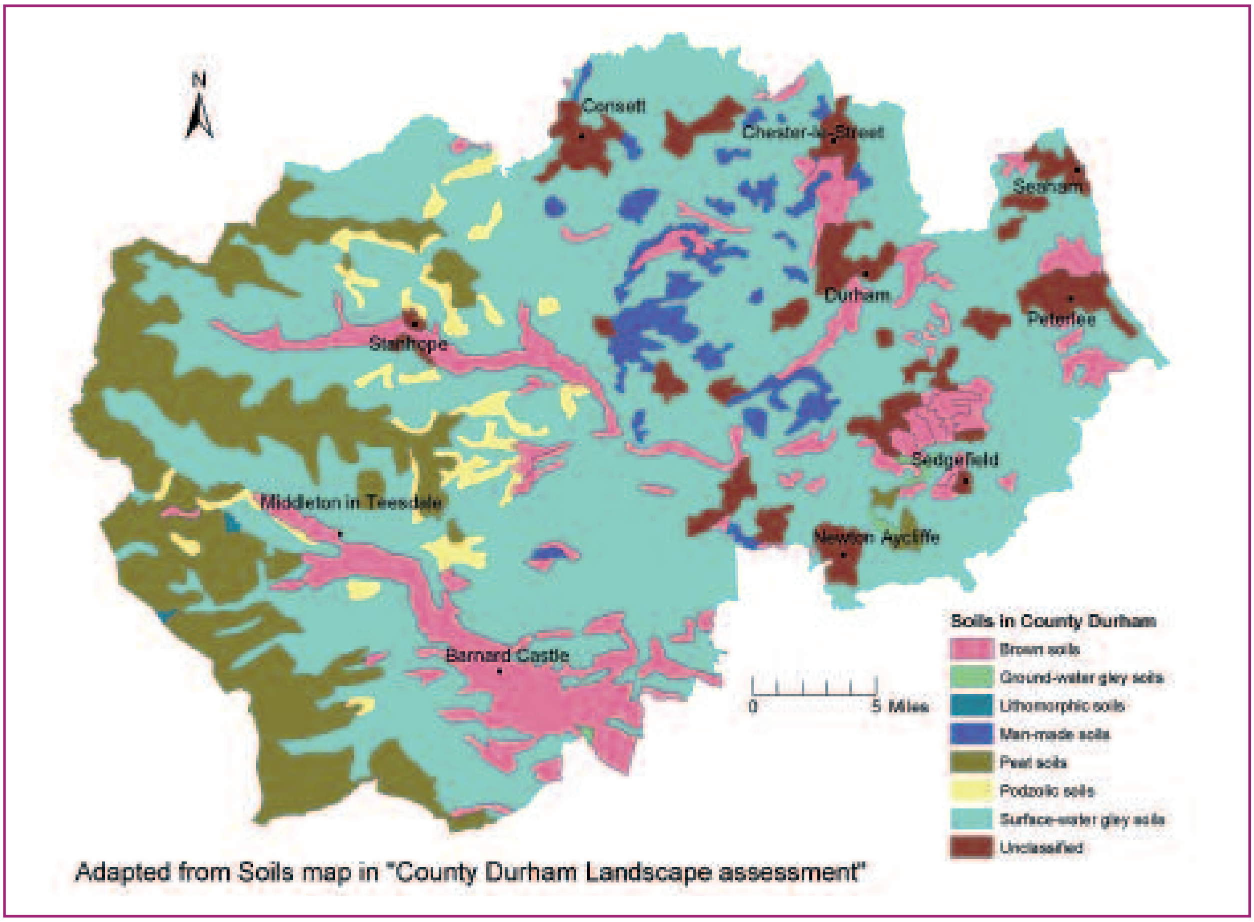


Figure 26. Distribution of soils in County Durham

Soils in County Durham

It has not been possible within the scope of this investigation of the county's geodiversity to explore in detail the nature and distribution of its soils. The map of soil distribution (*Figure 26*) and following brief description have been adapted from information in the 'County Durham Landscape Character Assessment'. More specialised information on soil character, properties and classification may be obtained from publications of the Soil Survey of England and Wales.

Soils over most of the county are heavy, poorly drained gleys derived from glacial boulder clays with pockets of lighter soils associated with glacial sands and gravels. Gley soils are characterized by a grey or grey and brown mottled (gleyed) horizon altered by reduction, or reduction and segregation, of iron as a result of periodic or permanent saturation by water in the presence of organic matter. Brown earths and alluvial soils occur along the main river valleys. Calcareous brown earths are found on limestone outcrops along the escarpment and coast.

In the west the combination of elevation, poor drainage and severe climate has lead to the development of extensive blanket bog of deep peat giving way on the drier eastern moors to thinner peats, humic gleys and podzols. Smaller pockets of earthy peats are found in the flat carrs of the Tees plain.

Substantial areas of land in the coalfield have been disturbed by opencast coal mining or the reclamation of derelict land and have either restored natural soils or rudimentary soils derived from shales and clays.

Selected references

Jarvis et al. 1984; Johnson and Dunham, 1963; Soil Survey of England and Wales, 1983.

FOSSILS AND PALAEONTOLOGY

***Fossils* are the preserved remains of animals and plants. Commonly only the hard skeletal parts or shell of an animal, or the most durable portions of a plant, are preserved as fossils, although exceptionally the original soft tissue may be replaced. The imprints in soft sediment of soft-bodied animals such as jelly-fish and worms may be preserved. The trails, tracks, burrows and feeding traces of a variety of animals are commonly preserved as trace fossils, as are the burrows and casts of worms.**

***Palaeontology* is the study of ancient life. It is an essential tool in geology for the purposes of correlation, strata identification and establishment of sequences. *Palaeoecology*, the study of the associations of coexisting fossil species, enables interpretation of ancient environments. Palaeoecology offers one of many links between geo- and bio-diversity: it has been estimated that the vast majority of biological species recognised by science are extinct.**

Fossils in County Durham and their wider importance

Many of the principal fossil groups are represented within the sedimentary rocks of County Durham. Included are trilobites, brachiopods, graptolites, crinoids, corals, ammonoids, gastropods, bivalves, fish, amphibians, reptiles and plants.

Detailed lists of the fossils recorded from the county are quoted in many of the literature references cited in the bibliography.

Fossils from several parts of County Durham have considerable significance beyond the county.

The graptolites identified within the Ordovician slates of the Teesdale Inlier give important insights into the nature and evolution of rocks of this period in Great Britain.

The county's Carboniferous rocks contain a variety of fossils which provide valuable evidence for contemporary environments and ecosystems across Northern England and Europe. Of particular note are the coral-rich Frosterley Marble and the sponge-rich Chaetetes Band, both within the Namurian Great Limestone. Beds rich in the fossil alga *Girvanella*, within the Dinantian limestones have considerable importance for regional correlation.

Quarter Burn, the type locality for the Quarterburn Marine Band, taken as the base of the Coal Measures in North-East England lies in County Durham. The county's Coal Measures rocks have also provided important clues to the rich flora of Carboniferous times, including a number of remarkable petrified logs of *Cordiates*, an early ancestor of the modern conifers, found in 1996 in opencast coal workings near Great Lumley. The fossilised stump

Photo 68. Fossilised tree stump in Stanhope Churchyard, Weardale. Photographed in 1971, the site is now much overshadowed by trees.

of a Coal Measures tree is a well-known feature in Stanhope Church Yard.

County Durham is internationally renowned for its succession of marine Permian rocks, parts of which have yielded a wealth of extremely important vertebrate and invertebrate fossils.

Photo 70. *Synocladia virgulacea. A beautifully preserved reef-building bryozoan from the reef limestones of the Magnesian Limestone.*

The Marl Slate is locally rich in well-preserved fish, especially species of *Palaeoniscus*. Fine examples have been recovered from several sites in the east of the county. Middridge Quarry, which has yielded bones of the Upper Permian reptiles *Protosaurus*, and *Adelosaurus* together with the amphibian *Leptosaurus*, is regarded as Great Britain's finest Upper Permian reptile locality. The site has also provided Britain's most diverse assemblage of Upper Permian plant fossils, including the best British examples of the conifer families Ullmanniaceae and Majonicaceae, together with what may be the earliest British example of cycad foliage. The quarry is designated as an SSSI and GCR site. *Protosaurus* has also been found at Quarrington Quarry. Part of a skeleton of Coelurosaurus, a reptile believed to have been capable of gliding flight, and one of only a handful of such specimens known from Europe,

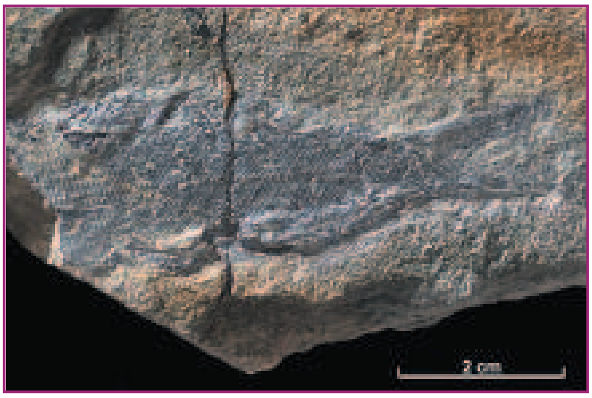


Photo 69. *Palaeoniscus sp. A well preserved fish typical of the Marl Slate.*

was discovered in 1978 in the Marl Slate at Eppleton Quarry, Hetton-le-Hole. Now within the City of Sunderland, Eppleton was then part of County Durham.

The Upper Permian barrier reef, present within the Ford Formation of the Magnesian Limestone of North-East England, has produced a rich and varied invertebrate fauna of international significance. Included are numerous brachiopod, bivalve, nautiloid and bryozoa species, together with rarer examples of echinoids and corals. Good exposures of the reef occur in County Durham, notably in the Easington and Blackhall areas. Some of the most fossiliferous localities, well-known from museum collections and publications, lay within the county when most of the collections were formed: these localities today lie within the City of Sunderland.

Threats

Collecting of fossils within the county is not currently perceived as threatening the scientific value of any sites, though inadvertant damage to key sections may result from inappropriate or careless use of these sites by educational or other groups. Careful and systematic recovery of fossils from certain geological units, for example the Marl Slate, in working quarries or temporary sections, has revealed much material of very great scientific significance.

The progressive deterioration of abandoned quarry faces, together with the risks of quarries being filled or landscaped may pose a threat to some important fossil localities.

Conservation

SSSIs or Durham County Geological Sites with important fossils are listed under *Ordovician*, *Carboniferous* and *Permian* rocks.

Museums with significant holdings of County Durham fossils are listed under *Geological Archives*.

Selected references

Benton and Spencer, 1995; Burgess and Holliday, 1979; Cleal and Thomas, 1996; Dunham, 1990; Dunham and Wilson, 1985; English Nature, 2000; Johnson, 1958, 1961, 1970, 1995; Johnson and Dunham, 1963; Mills and Holliday, 1998; Mills and Hull, 1976; Smith, 1970, 1981, 1994, 1995; Smith and Francis, 1967; Taylor et al. 1971.

MINERALS AND MINERALOGY

The strict scientific definition of a mineral is "A substance having a definite chemical composition and atomic structure and formed by the inorganic processes of nature". Individual minerals are generally referred to as species.

Rocks are composed of different minerals in varying proportions. Minerals may therefore be viewed as the essential components of rocks. Mineralogy is the study of minerals. Outside the science of mineralogy, the term mineral is widely used to describe any natural product won from the earth. Thus, although sandstone, coal, iron ore, and sand and gravel, are all commonly referred to as mineral products, they do not fulfil the strict definition of a mineral. This section is concerned with mineral species as defined above.

Minerals in County Durham and their wider importance

Approximately 130 valid mineral species are reliably reported in the scientific literature from County Durham. Many of these are known mainly, or solely, as components of rocks within the county. However, many are found within the mineral veins or related deposits within the Northern Pennine Orefield.

In common with most parts of Great Britain, no comprehensive topographical inventory of the minerals and their occurrence exists for County Durham.

The veins and associated deposits of the Northern Pennine Orefield have long been a source of beautifully crystallised examples of many of the more common of their constituent minerals. Perhaps best known of these is fluorite. The area has yielded some of the finest examples of this species known anywhere in the world. Striking examples are to be found in most of the world's major museum collections, and are described and figured in many mineralogical publications. Most spectacular are the brightly coloured crystals which have been recovered from mines, most notably in Weardale. Boltsburn Mine at Rookhope is probably one of the world's most famous localities for beautifully crystallised examples of fluorite, though Blackdene, Cambokeels and Frazer's Hush fluorspar mines also became important sources of striking crystals in the second half of the 20th century.

Photo 71. Crystals of purple fluorite from Boltsburn Mine, Rookhope.

Most common were purple crystals in a variety of hues, though yellow, colourless and green crystals were also found. Particularly fine examples of deep bottle-green fluorite are well known from the abandoned underground workings of Heights Mine, formerly exposed during limestone quarrying at Heights Quarry, and now mostly quarried away. Similar specimens occur, in some abundance, in a small vein in Eastgate Quarry. Commercial mining for fine fluorite specimens, mostly of a rich deep green or purplish green colour, continues today at Rogerley Mine, near Frosterley.

The widespread abundance of barium carbonate minerals is a feature which makes the Northern Pennines unique in the world, though the reasons for their comparative abundance here has yet to be determined. Most abundant is the barium carbonate, witherite, which is a major constituent of many of the veins in the outer zones of the field. There is strong evidence that this mineral was first recognised as a species within the Northern Pennines, almost certainly from specimens originating in the Alston Moor area. Elsewhere in the world witherite is an extremely uncommon mineral. In the Northern Pennines it is present in such abundance that it was for many years worked commercially as a raw material for the chemical industry. Within County Durham substantial deposits of witherite occur in veins of the Northern Pennine suite of deposits hosted within the Coal Measures rocks of the coalfield. For many years witherite was mined from such deposits, especially at South Moor. Also present in the Northern Pennine veins, locally in some abundance and in places closely associated with witherite, are the even rarer double carbonates of barium and calcium alstonite and barytocalcite. A few specimens of alstonite were recovered from the baryte/ witherite vein at New Brancpeth Colliery. Fine examples of witherite were obtained from both the South Moor and New Brancepth workings. Unusually fine, large crystals of the uncommon nickel mineral ullmannite were also found at New Brancpeth.

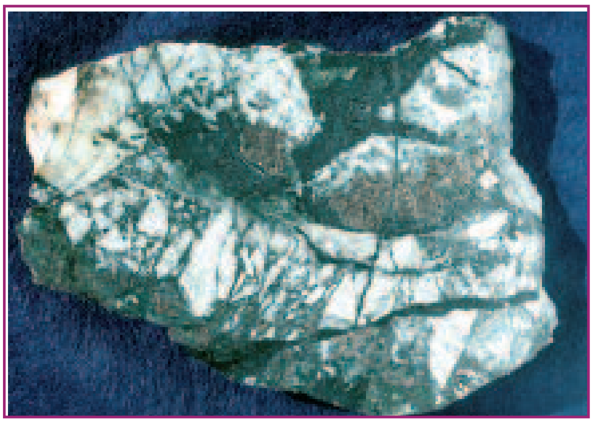


Photo 72. Polished slice of the unusual niccolite (copper coloured), magnetite (black) ore from Lady's Rake Mine, Teesdale. (The specimen is about 10cm across).

Other minerals, found in particularly fine specimens, or in unusual or interesting assemblages, within the county include apophyllite and pyrrhotite crystals from Cambokeels Mine, Weardale; cerussite from Stanhopeburn and Redburn Mines, Weardale; niccolite from Lady's Rake Mine, Teesdale; and leadhillite from Closehouse Mine, Lunedale.

An unusual suite of iron sulphate minerals, including ferricopiapite, sideronatrite and jarosite, has recently been identified in colliery spoil on parts of the Durham coast at Hawthorn and elsewhere.

Threats

Fine examples of several species, notably fluorite, have long attracted collectors and good examples are increasingly scarce, even at localities formerly well known for them. However, many of the area's most common minerals remain abundant at numerous localities.

The progressive depletion of important sites by continued uncontrolled collecting is addressed below (*page 168*).

Backfilling, or reclamation, of abandoned quarries may destroy important exposures of mineralisation.

Conservation

SSSIs or Durham County Geological Sites with important fossils are listed under *Mineral veins and flats*.

Museums with significant holdings of County Durham minerals are listed under *Geological Archives*.

Selected references

British Geological Survey, 1992, 1996; Dunham, 1990; Dunham and Wilson, 1985; English Nature, 2003; Fairbairn, 2003; Hacker, 2003; Wallace, 1861; Young, 1997, 2001, 2003.

GEOPHYSICS

Geophysics is the study of the physical properties of geological materials and structures.

The modern science of geophysics embraces a very wide range of often extremely complex and sophisticated techniques for measuring such parameters as gravity variations, magnetic properties, natural radiation and seismic properties. Study of these enables interpretation of the form and nature geological structures, often at considerable depths beneath the surface, and the processes which may have created them.

An area's geophysics must therefore be viewed as another aspect of its geodiversity.

Geophysics in County Durham

Much of our understanding of the deep structure of North-East England is derived from interpretations of a number of geophysical parameters.

In this section only those aspects of the area's geophysics which have most obvious impact upon geodiversity are considered. Key literature references from the substantial technical literature on the geophysics of Northern England, including County Durham, are listed in the bibliography.

During the 1950's, the North Pennines was a focus for early work on studies of gravity variations, stimulated by hypotheses which had earlier been proposed to explain the origin of the area's mineral veins. Certain key similarities between the mineral veins of the Northern Pennines with those of Devon and Cornwall led to speculation on the possible presence beneath the Pennines of a substantial body of granite. A detailed gravity survey of the Northern Pennines revealed a pronounced pattern of negative Bouguer anomalies which provided strong supporting evidence for a concealed granite. Drilling of the Rookhope Borehole in 1960-61 confirmed the presence of the Weardale Granite within the depth range suggested by the geophysical studies.

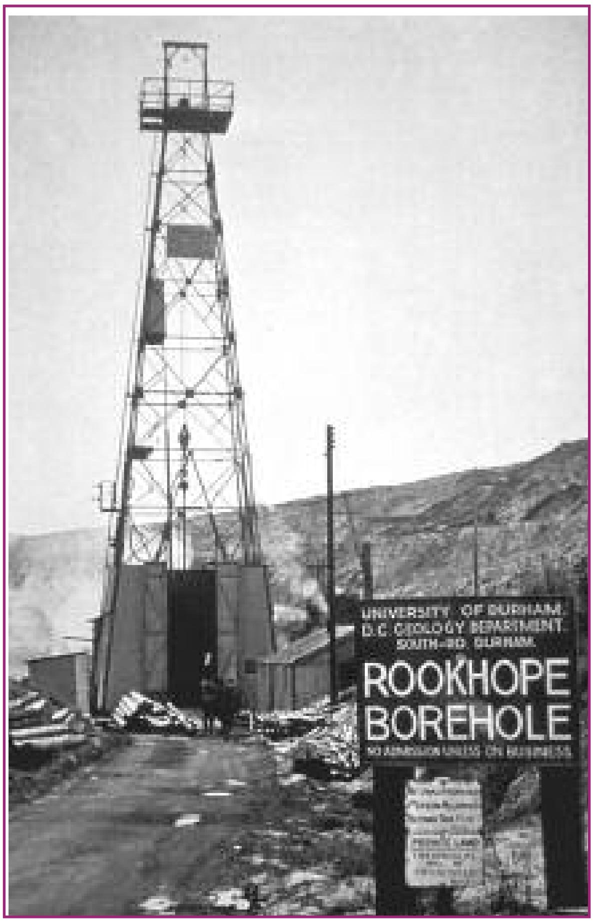


Photo 73. Rookhope Borehole, 1960-61.

The demonstration of the close genetic relationship between the distribution of minerals in the Northern Pennine veins with the form and extent of the concealed Weardale Granite, represents one of the area's most important contributions to the understanding of similar orefields worldwide.

The pattern of Bouguer anomalies associated with the Weardale Granite are clearly discernible on the Gravity maps of the British Geological survey.

Magnetic anomalies due to iron-rich basic igneous rocks such as the dolerite of the Whin Sill offer a useful means of inferring the presence of such rocks at depth or where concealed by superficial or other geological materials. Interpretations of magnetic anomalies associated with these rocks have contributed greatly to research into the concealed form and likely origin of the Whin Sill within County Durham. Evidence from such studies fails to support suggestions that the Whin Sill may have been emplaced via a feeder beneath Upper Teesdale, but gives evidence for the emplacement of this suite of intrusions through the major bounding faults of the Alston Block, such as the Lunedale and Stublick faults.

The Whin Sill and associated intrusions are readily discernible on the Aeromagnetic maps of the British Geological Survey.

A number of seismic profiles, mainly through areas immediately adjoining the county, give important evidence for the deep structure of the Alston Block.

Selected references

Bott and Masson-Smith, 1953: Bott and Johnson, 1970; Dunham, 1990; Dunham and Wilson, 1985.

GEOCHEMISTRY

Geochemistry is the study of the chemistry of geological materials.

Geochemistry is an important tool in investigating the detailed composition of geological materials, as well as facilitating interpretations of the processes which have formed, and continue to influence, these materials. A range of analytical techniques in isotope geochemistry provide a range of methods for dating geological materials. Studies of regional geochemistry are important in mineral exploration and offer important means of investigating the distribution and dispersal of chemical elements in the environment.

An area's geochemistry must therefore be viewed as an aspect of its geodiversity.

Geochemistry in County Durham

Geochemistry contributes greatly to our understanding of many aspects of County Durham.

In this section only those aspects of geochemistry which have most obvious impact upon geodiversity are considered. Key literature references from the substantial technical literature on the geochemistry of Northern England, including County Durham, are listed in the bibliography.

Significant research on the geochemistry of minerals and mineral assemblages from the ore deposits of the Northern Pennine Orefield have

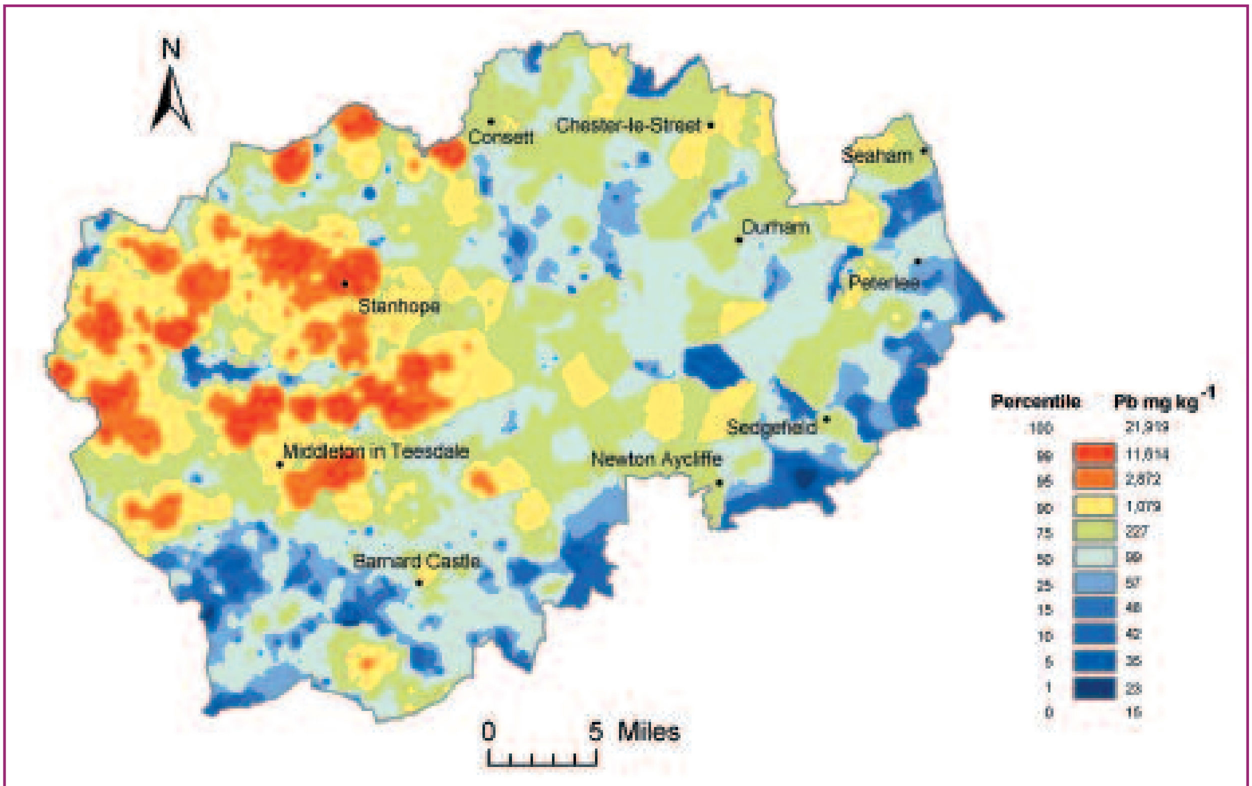


Figure 27. The distribution of lead in stream sediment and soil over County Durham

greatly advanced understanding of the nature and origins of these deposits, including the framing of important hypotheses on the origins of similar deposits worldwide. Particularly significant has been work on fluid inclusions and concentrations of rare earth elements.

Advances in isotope geochemistry have been applied to determining the absolute ages of the Whin Sill and Weardale Granite.

The distribution of a large range of chemical elements in stream sediments and stream water across the county, as determined by the British Geological Survey, is depicted in two Geochemical atlases. A geochemical image, typical of those in the atlases, is illustrated in Figure 27. In addition to indicating patterns of natural dispersion which may inform understanding of the local and regional geology and aid mineral exploration, these give important insights into the anthropogenic dispersion of a variety of elements, including those related to former coal and metal mining, and iron and lead smelting.

The lead map (Figure 27) is dominated by the influence of mineralisation in the Carboniferous rocks, especially the ore-deposits that are strongly enriched in the element. In this area, the spread of colliery waste over the Durham Coalfield and of spoil from the Northern Pennine Orefield have had a very substantial influence on the regional geochemical patterns.

The distribution of chemical elements may inform and explain aspects of biodiversity.

Selected references

British Geological Survey, 1992, 1996; Say and Whitton, 1981.

USE OF THE RESOURCE

EXTRACTIVE INDUSTRIES

County Durham has a very long and distinguished history of mineral production. A very wide range of mineral products has been worked within the county. Mining and related industries have had a substantial impact on the character of parts of the Durham landscape and the way it has been perceived. Perhaps the most abiding images of the county are as an industrial landscape of coal mining, lead mining, steel making and railways, at the heart of the industrial revolution. Despite the enormous importance of coal, for which the county is perhaps best known, the significance of other mineral products won from the county's rocks must not be underestimated.

Coal

To many people the county's name is virtually synonymous with coal mining. This industry, more than any other, has been of fundamental importance in shaping the landscape, economic, political and cultural heritage of the central and eastern parts of the county. Underground coal mining has now ended and opencast extraction is today a mere shadow of even a few years ago. Ambitious land reclamation projects have removed the most obvious scars of mining and a visitor to many parts of the county today will find scant evidence that this was once one of the world's greatest sources of coal. However, aspects of the legacy of centuries of coal mining do still pervade large areas of the county, though many of these are comparatively inconspicuous, certainly to a casual observer. Evidence for this once

Photo 75. Knitsley Opencast site during working
ex-Opencast Executive Collection now deposited with BGS.

Photo 74. Area of Knitsley Opencast site, before working.
ex-Opencast Executive Collection now deposited with BGS.
The white box shows area of photo 75

great industry today lies mainly in the pattern of scattered coal mining settlements, often with 'colliery' included within their names. Less apparent are areas affected by continuing surface instability, or the discharges of iron-rich mine waters. The Durham coast, once freely used as a place to dispose of vast quantities of colliery waste, has been largely cleared, though pockets of spoil still remain in a handful of localities.

Not only have some of the most obvious signs of coal mining been obliterated but, as discussed above (*see Westphalian Rocks*), tangible evidence of the very rocks from which the coal was won are increasingly difficult to see within the county.

Ironstone

The Coal Measures rocks of the county locally contain significant concentrations of sedimentary ironstones, mostly in the form of 'clay ironstone' nodules or as beds of 'black band' ironstone. Many of these are likely to have been worked in early centuries, though they formed the basis for the major iron smelting industries developed during and after the industrial revolution. Such iron ores were worked either alone or as by products of coal mining. It was the availability of such ores, together with the closeness of coal suitable for smelting, which led to the establishment of major iron making centres at Consett, Tow Law, and Spennymoor.

Substantial quantities of iron ores occur in association with the lead-bearing veins of the Northern Pennine Orefield. These too are likely to have been worked at an early date, but attained their greatest importance in the 19th century when large quantities of ores from several mines in Weardale also supplied the furnaces at Consett, Tow Law, and Spennymoor.

The Northern Pennine Orefield

County Durham includes a substantial proportion of the richly mineralised area of Carboniferous rocks, known as the Northern Pennine Orefield (*see Mineral Veins*). Although the main concentration of deposits within this orefield lies within the Pennine dales of Teesdale, Weardale and the Derwent Valley, related mineralised veins extend into the Durham Coalfield. Although not productive of metal ores in the coalfield, several substantial deposits of barytes and witherite were worked alongside coal.

Some of the earliest documentary records of mineral working within the county, which date back to the 12th century, refer to the mining of minerals such as iron and lead ores in the Pennine dales. Earlier mining for metals is possible, or even probable, though there is no proof of this. It is, however, reasonable to suppose that mineral products have been worked in the county since the earliest days of human occupation.

Most prominent of these ores was lead ore, or galena, mining for which was to impact heavily upon almost every aspect of the natural and human landscape of the Durham dales. During the 18th and 19th centuries the Northern Pennines was one of Britain's main sources of lead, and one of the world's most significant producers of the metal. Many mines, large and small, worked lead ore, often from veins in remote locations in the Pennine hills and dales. Smelting was originally undertaken close to the mines, but in the later years of the industry the ores were taken to smelters outside of the county.

Substantial amounts of silver were recovered as a by-product of lead mining and smelting. Suggestions that silver may have been the chief metal worked in early centuries from now lost silver-rich lead deposits ores cannot be reliably substantiated.

Although small concentrations of copper ores are known to occur in a few veins in Weardale, there are no records of working of these ores in County Durham, though small amounts of copper ores were worked from veins in the Garrigill area, a short distance west of the county border.

In addition, small amounts of zinc ores are known to have been worked commercially within the county.

The non-metalliferous minerals fluorite, baryte, witherite and quartz, found as 'gangue' minerals in association with metal ores, have been worked commercially in the county.

County Durham played a major role in the development of the world fluorspar industry. Long regarded as a waste product of lead mining, this mineral became a vital raw material for use as a flux in the steel industry in the closing years of the 19th century. Demand for Durham fluorspar grew in the early years of the 20th century, both for steel making and for a developing range of uses in the chemical industry. Mining and exploration for new reserves continued intermittently throughout much of the 20th century, though the availability of cheap fluorspar from sources such as China in the 1980s and 90s dealt a fatal blow to the Durham fluorspar industry. The county's last fluorspar mine, at Frazer's Hush in Rookhope, closed in 1999.

The barium minerals barytes and witherite are common gangue minerals in the outer zones of the Northern Pennine Orefield, which encompasses parts of the Durham Coalfield. Deposits of both minerals have been worked from several Durham collieries. County Durham shares, with Northumberland, the distinction of being one of the few places in the world where witherite was mined commercially as a raw material for the chemical industry.

A few tons of quartz are understood to have been extracted in Weardale for specialised use in the chemical industry.

To some extent mining of fluorspar, barytes and witherite helped offset the catastrophic economic consequences of the collapse in world lead prices which devastated the Durham lead mining economy at the close of the 19th century, though mining for these minerals never replaced the economic importance of lead mining to the communities of the west Durham dales.

Bulk minerals

Rocks currently, or formerly, worked from the county are:

Dolerite ('Whinstone'), Limestone, Dolomite,

Sandstone (including ganister), Shale and brickclay, Fireclay, Sand and gravel, Peat, Slate.

Dolerite from the Whin Sill, and from the Cleveland Armathwaite Dyke has been worked at numerous sites for aggregate and roadstone. Working of these rocks today is confined to the Whin Sill at Force Garth Quarry, near High Force.

Most of the individual **limestones** in the Carboniferous succession of the Pennines have been worked, mainly on a small scale, for making quick-lime and mortar. Large scale extraction in County Durham has been focussed on the Great Limestone. Huge quarries around Stanhope and Frosterley supplied limestone flux to the steel industry, as well as large quantities of crushed limestone aggregate. The same limestone provided the main raw material for cement making at Eastgate until the closure of this works in 2001. Extraction of Great Limestone, for use as aggregate and roadstone continues today at Heights Quarry in Weardale, and at Selsett Quarry in Lunedale.

The county's Carboniferous limestones have been little used as building stones, except for very local use in drystone walls. However, the

Frosterley Marble has been much used locally, and outside the county, as an ornamental stone (*see Built Environment and Extractive industries*).

The Permian Limestones of eastern County Durham have long enjoyed a variety of uses. From early times the pale cream coloured limestones of the Magnesian Limestone have been much used for local building. Indeed, their use as building stone imparts a distinctive character to the built environment of the eastern part of the county. As most of the limestones are in reality either **dolomites** or **dolomitic limestones**, they have long been important raw materials for the chemical industry. Large tonnages of Permian limestones and dolomites are still extracted today to supply the chemical industry and also as a major source of aggregates.

Substantial portions of the county's succession of Carboniferous rocks, both in the Pennine dales and the Durham Coalfield, comprise **sandstone**. Several of these sandstone units have been employed as building stone. Much of the stone is of unremarkable or indifferent quality, appropriate only for local use in vernacular architecture or drystone walling, though it is this use which lends much character to the county's built environment. However, certain beds of sandstone are of more consistent quality and thickness and have been more widely employed for construction. Notable examples include the Low Main Post sandstone from the Coal Measures, from which substantial parts of Durham Cathedral are built. Other sandstones from the Lower Carboniferous succession are still worked on a considerable scale at quarries in the Stainton area for use within the county and beyond.

A number of Lower Carboniferous sandstones exhibit closely-spaced bedding or lamination making them eminently suitable as roofing stone. Many dales cottages are roofed with such sandstone flags, though no sources of this material are worked within the county at present.

Certain silica-rich sandstones possess refractory properties which attracted their use in the making of furnace linings. The term '**ganister**' is commonly applied to such rocks. 'Ganisters' commonly, though not invariably, occur as 'seatearths' beneath coal seams, or the horizon of former coal seams. Such sandstones were formerly worked from numerous quarries within the Carboniferous rocks of the Pennine dales and Coalfield.

Some poorly-cemented sandstones are friable rocks suitable for use as **moulding sands** in the foundry industry. They have been worked from several quarries within the Carboniferous rocks of the Pennine dales and Coalfield.

A wide variety of **shales and siltstones** are suitable for the production of ordinary bricks. Several beds of such rocks within the Coal Measures have been employed in this way and brick production continues today at Ambion Brickworks using Coal Measures shale. Brick works were operated by some collieries, using waste shale of suitable composition.

Mudstone seatearths suitable for the making of refractory wares are normally termed '**fireclays**'. They were often worked as by-products in coal mining, both during underground mining, and in more recent years during some opencast operations.

Uncemented, or very weakly cemented, sands at the base of the Durham Permian succession, known as the Yellow Sands, have long been valued as **building sands**. They are worked today from several large quarries along the escarpment of the Permian rocks.

Glacial deposits and some alluvial deposits, locally contain reserves of **sands and gravels** suitable for construction use.

Peat forms a widespread mantle, in places several metres thick, over substantial areas of the higher Pennine hills. Although no longer of economic interest, these peat deposits provided an important local source of fuel for lead smelting.

The county's sole exposure of Ordovician **slates**, at Pencil Mill, near Cronkley in Upper Teesdale, is an old quarry formerly worked for the making of slate pencils.

Not only have these extremely varied mineral resources played a key role in the county's economic development, but they are clearly important elements in the area's geodiversity. Past and present workings offer a variety of opportunities to appreciate these.

The vital role played by mineral extraction in the geodiversity of the county is considered under the following headings:

Abandoned quarries
Active quarries
Abandoned underground mines
Active underground mines
Spoil heaps.

ABANDONED QUARRIES

Photo 76. Bollihope, Weardale. Abandoned quarries in Great Limestone.

Whereas the county's long and distinguished history of mineral extraction has left a legacy of many hundreds of abandoned quarries, there is no comprehensive register of their whereabouts and it is not currently possible to depict them on a map. However, certain geological units or formations have attracted particular economic interest. Numerous substantial quarries mark the outcrops of the Great Limestone, the Whin Sill and Palaeogene dykes, several of the Carboniferous sandstones, the Permian 'Yellow Sands' and Magnesian Limestone, and glacial sands and gravels. Smaller pits, often worked only for very local use, are also common. In building dry-stone walls and farm buildings it was common practice to obtain stone from as close as possible to the construction site. Thus, small pits are common alongside many lengths of wall, or close to farms or hamlets. Some of the county's mineral veins and related flat deposits were worked by quarrying. Peat is known to have been extracted on a substantial scale in the past, though none of these workings can be reliably identified today. Abandoned quarries may be regarded as essential and distinguishing features of the present day landscape in many parts of the county.

As disused quarries provide some of the most important, and several unique, sites at which certain rock units may be seen, they contribute greatly to the area's geodiversity.

Abandoned quarries may also be extremely important biodiversity sites. In some instances their biodiversity interest may be significantly greater than their geodiversity interest. Quarries can provide an opportunity to study the natural revegetation of an area. Abandoned quarry floors and faces offer a variety of substrates for rare or specialised plant communities, including sites for lichens and other lower plants. Whilst disused quarries can provide a refuge for many grassland plant species, it takes many years for the vegetation to develop. Under these circumstances unless there is a seed source reasonably close by from which plants can invade, then some species will be unable to take advantage of the new habitat and could become lost from the area altogether. Old quarries frequently offer excellent nest and roost sites for a variety of bird species, and may provide important bat roosts. Flooded quarry workings may offer important water bodies for aquatic life and a variety of bird species, including migrants.

Abandoned quarries are commonly seen as eyesores or convenient sites for waste disposal. Overgrowth of vegetation may spoil, or eventually totally obliterate, useful or important geological features. Reclamation schemes aimed at remediation of land affected by mineral extraction may destroy important or unique material.

Restrictions associated with the scheduling of abandoned quarries as historical monuments may seriously compromise the geodiversity value of the quarry.

Abandoned quarries commonly offer significant opportunities to demonstrate and interpret key features of the area's geology though, in the long term, some form of planned management, e.g. periodic clearing of vegetation, may be appropriate.

The educational and interpretational value of many abandoned quarries may be greatly enhanced by integrating their other interests, e.g. wildlife or archaeological significance, into educational or interpretational initiatives.

ACTIVE QUARRIES

Photo 77. Dun House Quarry, Stainton. Namurian sandstone worked as building stone.

These comprise quarries at which mineral products are being produced, or at which planning permissions exist to allow such extraction.

Carboniferous Limestone is extracted at several quarries. The bulk of this is used as crushed rock aggregate or roadstone. Large blocks are recovered for use as armour-stone. Some finely crushed limestone is used for agricultural purposes. A small amount of coral-rich limestone from the Frosterley Band within the Great Limestone is recovered from Broadwood Quarry in Weardale for use as ornamental stone.

Magnesian Limestones are worked from several large quarries in the east of the county. By far the greatest proportion is employed as crushed rock aggregate or as fill and sub-base material in road making. Substantial amounts of dolomitic limestone were formerly employed in the chemical industry, particularly in the making of refractory products, though this use has declined markedly in recent years.

Dolerite ('whinstone') from the Whin Sill is worked as an important source of roadstone from Force Garth Quarry in Teesdale. Large blocks are recovered for use as armour-stone.

Sandstone is worked as a building, paving and walling stone from several quarries.

Sand for use in the building and construction industries is worked on a large scale from the Permian 'Yellow Sands', often within the same quarries worked for Magnesian Limestone.

Brick clay is produced from Quaternary clays near Birtley. Coal Measures shales are currently worked for brickmaking at quarries in the Bishop Auckland area.

Active quarries provide fresh, and constantly changing, sections through the deposits worked. They thus provide some of the finest opportunities to further understanding and appreciation of the area's geodiversity.

Quarries inevitably make an impact upon the landscape, though modern operations are subject to planning and environmental conditions and requirements to mitigate this impact.

Active quarries may present significant opportunities for wildlife. For example, some quarry faces, particularly those not currently being actively worked, may offer roosting and nesting sites for a variety of bird species. The associated spoil heaps may provide substantially undisturbed habitats for a wide range of plant and animal life. Flooded portions of workings may offer important water bodies for aquatic life and a variety of bird species, including migrants.

Active quarries offer opportunities to demonstrate the working techniques, and relevance of these industries within their local and regional communities.

Significant opportunities exist at many active sites to plan after-uses which may be sympathetic to the preservation and exploitation of important geological features. With appropriate planning for after-use many quarries can become considerable assets to the county's landscape and natural heritage.

ABANDONED UNDERGROUND MINES

Photo 78. Cambokeels Mine, Weardale. The original stone-arched horse level.

Abandoned underground mines, which remain accessible, enable examination of numerous geological features associated with the mineral deposits formerly worked there, many of which may be rarely exposed clearly at the surface. Underground sites often give unique opportunities to examine geological successions and structures in three dimensions and may offer the chance to study the mechanical and engineering properties of geological structures and materials. Many underground sites preserve geological features or materials in a comparatively unweathered condition, enabling comparison with surface exposures and therefore aiding understanding of a number of geological processes. Underground sites may also provide unique insights into the working practices adopted in mineral extraction. Abandoned underground mines thus contribute greatly to the area's geodiversity.

Centuries of coal mining have left many square miles of the county undermined, in places in several seams. In the Durham dales, an equally lengthy history of working of lead ore and associated minerals has resulted in many miles of underground driveages and stopes. Whereas very few old coal workings are accessible today, access to some of the North Pennine mines remains possible, though in most instances only to experienced underground explorers.

It is tempting to suggest that as these sites lie underground, concealed from all except a comparatively small number of underground explorers, that they are not relevant in considering the area's landscape. This argument cannot be sustained. In an area with such a long and distinguished history of underground working, underground workings comprise an element of the landscape as essential as any surface feature.

Like abandoned quarries, it is quite impractical to depict all abandoned underground workings on a map.

In addition to their contribution to the area's geodiversity, underground workings commonly exhibit substantial biodiversity importance. Many mine entrances and shafts are well-known and well-used bat roosts, and some such workings provide specialised habitats for a variety of invertebrates, especially in their near surface parts. Timber, used within the mines, may today host a range of fungal species.

Several of the county's accessible abandoned underground workings exhibit significant features of industrial archaeological or historical interest.

Abandoned underground workings attract the attentions of mine explorers, many of whom have no particular interest in the exposed geological features, as well as mineral collectors. Clearly, access to such potentially unstable workings raises important safety considerations.

By their very nature, underground workings are especially vulnerable to deterioration and progressive dilapidation of the workings and the access routes to them. It is many years since most of the currently accessible workings were actively worked. Their stability and security is therefore almost entirely dependent upon the physical properties of the rocks through which the workings are excavated, and the condition of any supporting structures placed by the original miners. It is common for mine explorers, and mineral collectors to attempt to regain access to long-inaccessible areas of workings by excavating through blockages etc. Such work is generally of an *ad hoc* type and may not be based on expert civil engineering practices and may threaten the long-term stability of the workings.

Collecting of mineral specimens constitutes one of the most serious threats to both the accessibility and scientific value of many underground geological sites (*see page 167*).

Two underground sites, Park Level Mine, Killhope, and the abandoned coal drift at Beamish Museum, are currently operated for public access and interpretation of mining and geological features.

Mine exploration groups may offer opportunities to monitor the condition of workings and to recommend necessary remedial work.

ACTIVE UNDERGROUND MINES

Photo 79. Groverake Mine, Rookhope. Loading fluorspar ore in the 60 Fathom Level. Photographed 1982.

Apart from one very small underground mine, currently worked seasonally to produce fluorite specimens for the collectors' market, mainly in the USA, from a small vein and associated flat deposits at Rogerley Quarry, Weardale, there is no active underground mining today in County Durham.

Like active quarries, active underground mines provide constantly changing sections through the deposits being worked. County Durham's sole active underground mine provides a unique opportunity to study a fluorite-rich deposit typical of several known in the Northern Pennines. The mine makes no significant impact upon either the landscape or biodiversity of the county.

Two underground sites, Park Level Mine, Killhope, and the abandoned coal drift at Beamish Museum, are currently operated for public access and interpretation of mining and geological features.

SPOIL HEAPS

Centuries of mineral extraction have left a varied legacy of mineral wastes in the form of spoil heaps from quarries, mines or mineral processing plants, including former metal smelting operations.

Photo 80. Lodge Sike Mine, Teesdale. Extensive spoil heaps from old lead workings.

Spoil heaps typically comprise the geological materials discarded as waste from the deposits worked and also contain examples of the materials worked. When derived from underground workings which are no longer accessible for study, these spoil heaps provide a unique source of evidence for the materials worked, or penetrated, in the workings. In some instances these may include important, in some instances unique, sources of certain minerals. Exposure to weathering in spoil heaps may enhance the value of the included materials. For example, many fossils which may be extremely difficult to see in an unweathered exposure or quarry face, may be clearly exposed in weathered blocks in a spoil heap. A number of supergene mineral species may be forming within spoil heaps, particularly in those from some collieries and former smelting operations.

Whereas a considerable variety of spoil heaps associated with mineral extraction may be recognised in County Durham, the following are particularly significant when considering geodiversity.

Colliery spoil heaps. Centuries of coal mining brought millions of tonnes of waste rock to the surface for disposal. Until comparatively recently large heaps of coal mine waste, mainly grey shale, were conspicuous features in the landscape of the coalfield. It was common practice at several coastal collieries to dispose of waste by dumping on the beach. Huge volumes of such waste accumulated on the Durham coast, overwhelming the natural beaches and disfiguring the coastline.

Photo 81. Hawthorn Hive, Easington. Colliery spoil accumulated on beach. The vivid yellow areas are crusts of iron sulphate minerals forming by weathering of the pyrite-rich spoil.

With the demise of coal mining, and a widespread programme of environmental improvements, most inland colliery spoil heaps have been subject to reclamation works. Many have been landscaped, covered in topsoil and either developed into amenity open spaces or planted with trees. Others have been largely backfilled into adjacent opencast coal workings. In comparatively few inland localities can significant amounts of colliery spoil be seen today.

The 'Turning the Tide' programme, administered by Durham County Council between 1996 and 2001, resulted in the clearance of vast quantities of colliery spoil from the Durham coast, though some areas of such spoil remain on the coast, for example at Dawdon and Easington.

Coal Measures shales are typically rich in pyrite and marcasite. In the presence of water these are unstable, leading to the formation of extremely acidic iron-rich groundwaters. This process of decomposition is accelerated in the presence of sea water. In consequence, significant amounts of acidic iron-rich water are today being leached from the accumulations of colliery spoil at Dawdon and Easington. In places, notably around Hawthorn Hive, partial evaporation during dry weather produces ephemeral encrustations of a range of rare iron sulphate minerals (*see Minerals and Mineralogy*) on the spoil and adjoining Magnesian Limestone cliffs.

Metalliferous mine spoil heaps. A long history of mining for lead, iron and associated minerals from the deposits of the Northern Pennine Orefield have produced numerous spoil heaps in the west of the county. Although substantial volumes of spoil have accumulated adjacent to some of the county's larger metalliferous mines and processing plants, such spoil heaps are generally very much smaller than those associated with the collieries of central and eastern Durham. These heaps typically contain a high proportion of waste wall-rock, though many contain an abundance of vein minerals discarded as uneconomic during mining. The rock and mineral fragments contained in spoil heaps from many of the county's former metalliferous mines offer the sole remaining evidence of the deposits worked and the constituent minerals. Metalliferous mine spoil heaps include accumulations of spoil from mineral processing operations. Typically these comprise concentrations of gravel or sand sized particles, mainly of vein minerals. Accumulations of slags and other smelter wastes are present at former smelting sites. Spoil heaps may be regarded as crucial resources in the county's geodiversity.

Spoil heaps are locally important elements in the county's landscape. Indeed, many of the spoil heaps associated with metalliferous mines may be viewed as essential elements which help to characterise and define those landscapes. In some places spoil heaps may give the only remaining clues to the presence of former workings.

Some spoil heaps provide an important habitat for a number of plant communities. These include limestone flora on the heaps adjoining some limestone quarries and metallophyte flora on numerous spoil heaps from metal mines and processing and smelting plants.

Spoil heaps may be rather vulnerable elements in the landscape. Removal of rubble for earthworks or track-making, or reclamation of spoil heaps may destroy or obliterate them. Such reclamation activities may include tree planting or top-soiling of the heaps, both of which effectively render the materials contained within the heap inaccessible for geological study. Natural erosion threatens a small number of scientifically significant spoil heaps. Collection of mineral specimens may seriously deplete the resource.

Several spoil heaps, particularly some associated with former metalliferous mines are included in the archaeological features scheduled at those sites. Scheduled Ancient Monument (SAM) designation normally precludes any form of disturbance, however minor, including the collecting of geological specimens. Where applied to spoil heaps this designation may effectively limit severely the geodiversity value of that spoil heap.

Fresh material added to spoil heaps associated with active mineral workings potentially increases the resource value of that heap. Potential exists for mineral operators to make portions of spoil heaps accessible for educational or recreational use by groups or individuals. Such activities may include setting aside concentra-tions of waste material of particular geological interest.

Excavation of a spoil heap offers important opportunities for recovery of significant material and associated recording of finds.

Spoil heaps may offer important potential for sustainable educational and recreational collecting.

Selected references

Atkinson, 1968; Burgess and Holliday, 1979; Dunham, 1990; Dunham and Wilson, 1985; English Nature et al. 2003; Fairbairn, 2003; Forbes et al. 2003; Galloway, 1882; Jevons, 1915; Mills and Holliday, 1998; Mills and Hull, 1976; North Pennines Partnership, 2001; Say and Whitton, 1981; Smith, 1994; Smith and Francis, 1967; Sopwith, 1833; Taylor et al. 1971; Wallace, 1861.

THE BUILT ENVIRONMENT

The built environment is the legacy of man-made structures throughout an area. It includes houses, farms, churches, grave yards, schools and other public, industrial and commercial buildings, roads, pavements, and drystone walls.

The built environment and geodiversity

The character of an area's buildings, especially in a rural area, is an element in its landscape as essential and distinctive as the shape of its hills, or the pattern of its vegetation.

The use of geological materials in buildings provides one of the most direct ways of recognising the link between the natural and human landscapes, and of appreciating the importance of the earth's resources through understanding the properties and limitations of these materials.

In addition, built structures may provide readily accessible opportunities to demonstrate a variety of rock types both from the area itself, and through the use of imported materials, a range of more exotic geological materials. Such materials may be both abundant and varied in urban situations. They are thus a potentially valuable educational resource.

The materials employed in the built environment may legitimately be regarded as another facet of the area's geodiversity.

Materials used in the built environment of County Durham

A variety of geological materials, derived from within the county, are employed in its buildings and structures.

Sandstone

One of the most widely used stones in the county is sandstone derived from various parts of the Carboniferous succession. Almost any reasonably durable sandstone can be pressed into service for wall construction and over much of the county sandstone of very local derivation appears to have been employed in most vernacular architecture.

For more significant buildings stone of a more consistent quality and appearance was normally

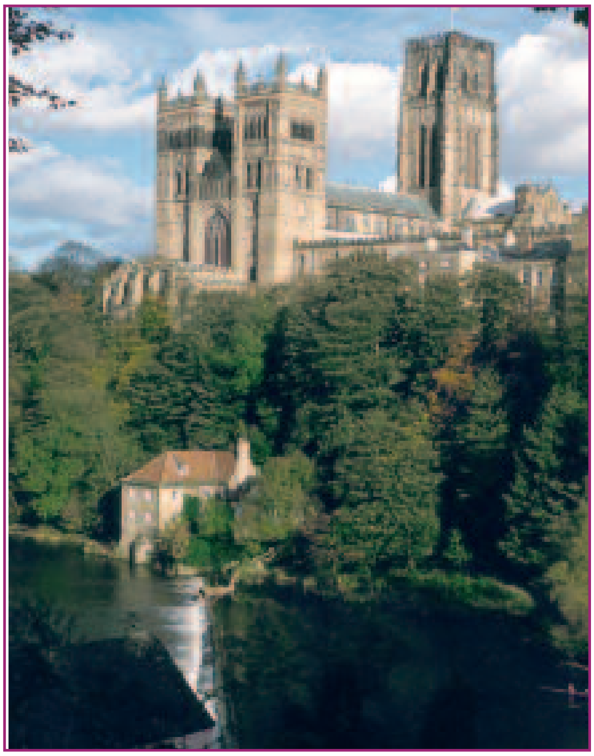


Photo 82. Durham Cathedral. A striking example of the use of Coal Measures sandstone (the Low Main Post) as a building stone.

required. The county possesses several sandstones capable of supplying significant quantities of stone of consistent quality. A prominent early example of such a use of stone was in the building of Durham Cathedral. Here sandstone from the Low Main Post, a sandstone above the Low Main Coal of the Coal Measures, was employed. Over the succeeding centuries a variety of other Carboniferous sandstones became favoured as good quality building stones. The county abounds in examples of their use. Significant quantities of such sandstone are still quarried today, with substantial quantities being employed in building and repair programmes throughout Great Britain. A notable example is the use of sandstone from Dunhouse Quarry, near Staindrop, for repair work in Edinburgh where sources of the original Scottish sandstones are no longer available.

A feature of many Northern Pennine villages and farms, in the west of the county, is the use of sandstone slabs for roofing. The number of quarries able to provide these was much more limited than those which could provide walling stone. Although some long-abandoned roofing slab quarries can still be identified, the whereabouts of most of is now lost. One small quarry, at Ladycross, a short distance outside the county, continues to produce slabs suitable for roofing. This quarry is likely to have been the source of roofing material for several buildings in the north west of the county.

A major use of building stone in the 18th and 19th centuries was in lining and supporting shafts and adit levels in the county's lead mines. The county abounds in fine examples of the highly skilled craftsmanship used in constructing the linings to many mine entrances and tunnels. Very considerable care was thus given to their, design, construction and selection of the materials used. Waste rock from the mines was rarely, if ever suitable. Instead, specially quarried stone was taken underground for the purpose. Rather flaggy sandstones, capable of yielding parallel-sided slabs, were preferred. Quarries from which such stone was obtained can be identified close to many mines.

Enormous quantities of sandstone, much of it of indifferent quality, were employed in building the countless miles of drystone walls throughout the western parts of the coalfield and Pennine dales. Such stone was generally obtained from numerous small pits along the line of the walls' construction.

Limestone

Despite the comparative abundance and accessibility of many of the Carboniferous limestones of the Pennine dales, Carboniferous limestone is little used in buildings in the county. It seems likely that sandstone provided a more abundant and easily worked building material. In these areas limestone appears to have been reserved for making of mortar.

The unique coral-rich limestone, The 'Frosterley Marble', obtained from the Great Limestone, has been an important source of ornamental stone. It was used for pillars and flooring slabs in Durham Cathedral as early as the 14th century. In addition to its use in making internal ornamental pillars in churches, it has been much used in making fonts, tombs and even wash stand tops. Examples of its use within County Durham include:

- Frosterley Church (font)
- Stanhope Church (font, table-top tombs, coffin)
- Eastgate Church (font)
- Wolsingham Church (chancel floor)
- Auckland Palace Chapel
- Durham Cathedral (extensively used as pillars in Chapel of Nine Altars, Chancel, Rood Screen, Gallilee Chapel, flooring)

It is commonly supposed that much of the stone employed in Durham Cathedral originated at Harehope Quarry, at Frosterley, though other sources may also have been exploited. It is however, worth noting that a few examples of the Frosterley Marble in the Cathedral exhibit a distinctive reddish brown colour, a-typical of much of the stone in known outcrops. This colouration is consistent with oxidation of iron carbonate mineralisation. Such colouring is locally conspicuous in parts of Harehope Quarry, giving strong support to the site as a source of this unusual form of the rock.

The dolomitic limestones and dolomites of the Magnesian Limestone in the east of the county, have been much used locally as a building stone. Indeed, the distinctive cream or very pale yellow colour of this stone is locally a characteristic element in the buildings and landscape of many east Durham villages, hamlets and isolated farms. Although such limestones from the equivalent Permian beds in Yorkshire have been used in such prominent structures as the Houses of Parliament, there seems little evidence of Permian limestones from County Durham being employed on any scale outside the county.

County Durham is today a major producer of limestone aggregate, obtained from both the Carboniferous limestones and the Magnesian Limestone. Large tonnages are consumed by the construction industry within the county and beyond.

Dolerite ('Whinstone')

Although an extremely durable rock, the dolerite of the Whin Sill has never been widely employed as a building stone, except in drystone walls on or close to its outcrops. This almost certainly reflects the hard, intractable nature of the stone, making it difficult to work.

Although rarely used for building, Whin Sill dolerite has long been employed as a good quality roadstone and for the making of setts and kerbs. Large abandoned quarries mark its outcrop in Teesdale and the related Little Whin Sill was formerly worked for the same purpose at Greenfoot Quarry in Weardale. Force Garth Quarry, close to High Force, is today a major producer of crushed Whin Sill dolerite for road surfacing. Many of the roads within the county are surfaced with tarmac-coated dolerite, obtained either from Teesdale or from Whin Sill quarries in Northumberland.

Clearance stones

Clearance stones from fields have locally been an abundant source of stone. Walls and buildings constructed from such stones can generally be recognised from the very varied nature of the stones and commonly the rather rounded outlines typical of boulders recovered from superficial deposits, in contrast to the angularity of freshly quarried blocks.

Photo 83. Durham Cathedral. Polished columns of Frosterley Marble contrasting with Coal Measures Sandstone in the Chapel of the Nine Altars.

Photo 84. Helmington Row, near Crook. Pale grey bricks produced from Coal Measures fireclay.

Brick

Bricks can be made from a comparatively wide variety of raw materials. Within County Durham bricks have traditionally been made from glacial clays, or from clay-rich rocks within the Coal Measures succession. It was common for several collieries to support a brickworks which employed otherwise waste shale from coal mining. Fireclay, also typically obtained as a by-product of coal mining, was commonly employed for brick making as well as the manufacture of refractory products. Distinctive pale cream fireclay bricks are a feature of several colliery settlements.

Bricks are still made in the county today at Ambion Brickworks, near Bishop Auckland, using local Coal Measures shales.

Photo 85. Drystone wall built of limestone as host to a variety of lichens and mosses. God's Bridge, Bowes Moor.

Sources of local geological materials in County Durham

Where natural outcrops of reasonably durable stone are frequent in rural areas, it was common practice to use the closest available stone source when building farm buildings or even small groups of cottages. Materials have often been sourced extremely locally, commonly from the same farm or even the same field in which they are used. Small quarries are common near many farms and hamlets.

The builders of the many miles of drystone walls typically sought stone as close to the construction site as possible. A feature of many walls is the presence, at intervals along the course of the wall, of small pits from which stone was obtained, either from rock outcrops or from boulders within the superficial deposits. Particularly in valley bottoms, clearance stones from the neighbouring fields may have been important sources of stone.

In early centuries the demand for substantial quantities of stone of consistent quality for major construction projects such as castles and major churches, including Durham Cathedral, led to larger scale quarrying from stone sources which in some instances may have been comparatively distant from the construction site. Until the 20th century stone was the preferred construction material for much urban development, including the comparatively rapid growth of mining and related settlements. Numerous quarries were established to supply a rapidly increasing demand. Sandstones from the Namurian and Westphalian rocks, and limestone from the Magnesian Limestone were the main stones worked. As brick came to supplant stone as the main building material most of these quarries became abandoned. A few sandstone quarries survive today, supplying high quality stone for use both within the county and beyond.

Imported geological materials used in the built environment of County Durham

In most rural areas it was common practice to obtain building stone from the nearest available source. The more costly use of specially quarried stone from further afield was typically reserved for specialist purposes or high cost prestigious buildings. Such uses include the construction of churches or other notable public buildings, and the construction of commercial buildings in major towns. In such situations a very wide range of building stones from from outside County Durham may be seen.

Welsh slate is a widespread roofing material across much of the county, though locally obtained sandstone slabs are common in older buildings in the Pennine dales. Other sources of slate, e.g from the Lake District may be seen locally: such slate has recently been employed in re-roofing of parts of Durham Cathedral. Clay tiles are common, particularly in some southern parts of the county.

A variety of exotic ornamental stones, including many from overseas sources, may be seen employed in gravestones, and as ornamental stones in churches and other buildings.

Although not derived from within County Durham, stones sourced from outside the county may be regarded as offering another useful dimension to the geodiversity of the area.

Such materials may have been employed for specific purposes for which there are no suitable materials within the county. They may have been selected for aesthetic reasons.

Recognition of the exotic nature of such stones, and understanding their original sources, is important in studies of the built environment and may be of practical application in planning repair or restoration work.

The local presence of exotic rocks offers useful educational opportunities.

Influence on the landscape and biodiversity

The character of the built environment, and thus of the materials used, both in rural and urban situations, is an element in the landscape as essential and distinctive as the shape of the hills, or the pattern of vegetation.

Photo 86. Heighington Church. Churches and church yards such as this contain a variety of rock types.

Rocks in walls and buildings may provide important substrates for a variety of lower plants, including mosses and lichens.

Threats

Progressive deterioration of building stone, principally by weathering, may necessitate replacement of stone. Replacement with stone from the original source may be desirable. For important historic buildings re-establishing a source of stone from the original quarry or from the geological unit known, or believed, to have been the source of stone may be worth considering. Where the original source is unknown or no longer available, an alternative stone is required. This should be compatible with that being replaced. An understanding of stone characteristics and likely performance with time is essential to effective long-term repair and maintenance. Repairs with poorly matched or incompatible stone may result in accelerated deterioration to the existing fabric and may exacerbate maintenance problems.

Opportunities for conservation and interpretation

A variety of initiatives to restore and conserve buildings of all types within the county offer wide ranging opportunities to encourage the use, and re-use of local stone. Opportunities may exist to re-work former sources of stone for repairs or new building work.

It may be appropriate to explore the possibilities of sourcing stone for repair work on major historic buildings, such as Durham Cathedral, by re-opening the quarries which supplied the original stone or from quarries opened within the geological unit known to have been the source.

The use of stones in buildings and structures offers excellent opportunities to develop a variety of interpretation and educational initiatives to explore the essential links between geological features and natural landscapes and the human and social heritage of the county.

Use of local geological materials beyond County Durham

A variety of sandstones from County Durham have been employed in building projects outside the county. A notable use of County Durham sandstone is in building and repair work in Edinburgh. These sandstones may be similar to the Scottish stones originally employed, and which are no longer available.

The coral-rich ‘Frosterley Marble’ has been widely employed as an ornamental stone in adjoining parts of northern England and beyond. Frosterley Marble may be seen, employed as an ornamental stone, in York Minster, Truro Cathedral, the Roman Catholic Cathedral in Norwich, and as far afield as Bombay Cathedral.

Dolerite (‘whinstone’) from the Whin Sill of the county has long been employed as an important roadstone across much of northern England.

Selected references

Forbes et al. 2003; Johnson and Dunham, 1982.

UNDERSTANDING THE RESOURCE

COUNTY DURHAM'S PLACE IN THE DEVELOPMENT OF GEOLOGICAL SCIENCE

An appreciation of the evolution and development of geological understanding is an important element in an area's geological heritage and thus its geodiversity.

Geological science developed in large part from the observations and deductions made by practical miners, quarrymen and civil engineers, concerned with profitable mineral extraction and construction projects. Their observations and deductions relate to geological sites and features, some of which are still visible today.

The word 'geology' can trace its origins back to Durham in the 14th century (*see Conserving Geodiversity*).

Centuries of successful mineral extraction within the county have been possible only by the skilful application of hypotheses developed by systematic observation of countless unknown and forgotten miners and quarrymen. The need to develop a sound understanding of the local rocks and geological structures was of particular importance in the lead mining areas of the Durham dales and the coalfield. By the early 19th century several local figures emerge in the annals of contemporary scientific literature as significant leaders in the emerging science of geology.

Notable figures in the lead mining areas include Westgarth Forster, William Wallace and Thomas Sopwith. Although, as may be expected, many of their hypotheses are now outdated, and in some instances discredited, their contributions to the development of understanding of Northern Pennine geology are undeniable, and stand as important milestones in the wider development of geological science.

As one of Great Britain's longest worked coalfields, the Durham Coalfield contributed much to the development of mining practices and techniques. One of the most significant of these was the work to develop a safe method of mine lighting, prompted by the loss of 92 lives in a methane explosion in May 1812 at Felling Colliery, then in County Durham. Prompted by this, the latest in a long history of such disasters, a committee was appointed to improve ventilation and lighting of coal mines. One of the outcomes was the development of the flame safety lamp. Although this came to be known as the 'Davy Lamp' after Sir Humphrey Davy who conducted much research on the problems of methane, it is known that George Stephenson, of locomotive fame, was also pursuing a similar line of investigation contemporaneously with Davy.

Until the early years of the 19th century coal mining in the county was limited to the area of the exposed coalfield. Indeed, until then it was generally supposed that coal deteriorated in quality when followed beneath the limestone. It was William Smith, often dubbed the 'Father of English Geology', who at the invitation of Colonel Braddyll a County Durham coal owner, concluded that the Magnesian Limestone rested unconformably upon the Coal Measures and that workable coal was very likely to be present in substantial quantities. His ideas culminated in the successful sinking of Hetton Colliery to the Hutton Seam in 1820, heralding a new and extremely profitable era for coal mining in the county. Such sinkings were far from easy as they involved penetrating the water-bearing Permian 'Yellow Sands'. Techniques developed here to deal with such difficult and dangerous ground have influenced mining and civil engineering worldwide.

Photo 87. Sir Kingsley Dunham (1910-2001).

Throughout subsequent years the area has been a fertile source of inspiration for research. Although it is impossible to name all of the significant players, mention must be made of the seminal work of Sir Kingsley Dunham (1910-2001). It was he, together with research colleagues such as Martin Bott, who developed the hypothesis of a buried granite beneath the Pennines to explain the origins and nature of the mineral veins of the Northern Pennines. The proving of this granite in the Rookhope Borehole was to prove a major milestone in the evolution of thinking on ore-forming processes worldwide. The great international importance of the Permian rocks of County Durham, and their part in influencing the development of the North Sea oil and gas fields, owes much to the work of D.B. Smith.

It is also important to recall that the North of England has given geological science one of its most familiar terms. To the Northern Pennine miner a 'sill' was any more or less horizontal body of rock. The name 'whin', meaning hard, black and intractable, was applied to one particular unit. When, in the 19th century the intrusive igneous nature of the Whin Sill was recognised, the term sill was soon adopted worldwide for intrusive bodies of this sort. It is not known exactly where in northern England the term Whin Sill was first used by miners and quarrymen, though the Northern Pennines, including County Durham, seems highly probable.

Selected references

Challinor, 1971; Dunham, 1990; Forster, 1809,1883; Hutton, 1831; Jevons, 1915; Galloway, 1882; Sedgwick, 1829; Sopwith, 1833; Smith, 1994; Smith and Francis, 1967; Wallace, 1861.

ARCHIVES AND MATERIALS COLLECTIONS

A comprehensive review and evaluation of an area's geodiversity cannot be restricted to those geological features which exist on the ground, or which remain within the area. In a country like Great Britain, many years of geological observation, recording and research have created an enormous archive of information, published and unpublished, and collections of geological materials. Although these collections and archives may now reside at locations remote from the source area, they are, nonetheless vital parts of that area's geological heritage, and thus essential elements of its geodiversity. Such collections may include information on, or specimens from, locations or features which are no longer accessible or available for study: they may thus offer the sole means of investigating these parts of the area's geodiversity.

A knowledge of the scope and whereabouts of the most significant geological archives, relevant to County Durham, is essential to the successful implementation and future monitoring of geodiversity within the area.

In this section these archival sources are considered under the following headings:

Documentary sources
Materials collections

DOCUMENTARY SOURCES

The British Geological Survey

As the national geological survey, the British Geological Survey (BGS) has an incomparable archive of information and materials collections relating to County Durham, dating back to the earliest years of geological mapping and research in Northern England in the final quarter of the 19th century. County Durham has been a focus for studies by BGS (and its predecessors) over the succeeding years. At the time of writing the county remains an important theatre of research activity by BGS.

Information sources held by BGS include original field maps (field slips), published maps, memoirs, reports, open-file maps and reports, borehole records, mine plans, fossils, rock samples, thin sections, hydrogeological, geochemical, geophysical and geotechnical data and photographs.

The following BGS publications provide information on the surface geology of the county:

Geological maps

The following BGS geological maps cover, or include, parts of County Durham:

Small Scale Geology maps

1:625 000 scale

United Kingdom North Sheet, Solid geology, 1979

United Kingdom North Sheet, Quaternary geology, 1977

1:250 000 scale

54N 04W Lake District, Solid geology, 1980

54N 02W Tyne-Tees, Solid geology, 1986

Medium Scale Geology maps (*see Figure 28*)

1:63 360 scale

Sheet 27, Durham, Solid and drift, 1965

Sheet 32, Barnard Castle, Solid and drift, 1969;

Solid with drift, 1969

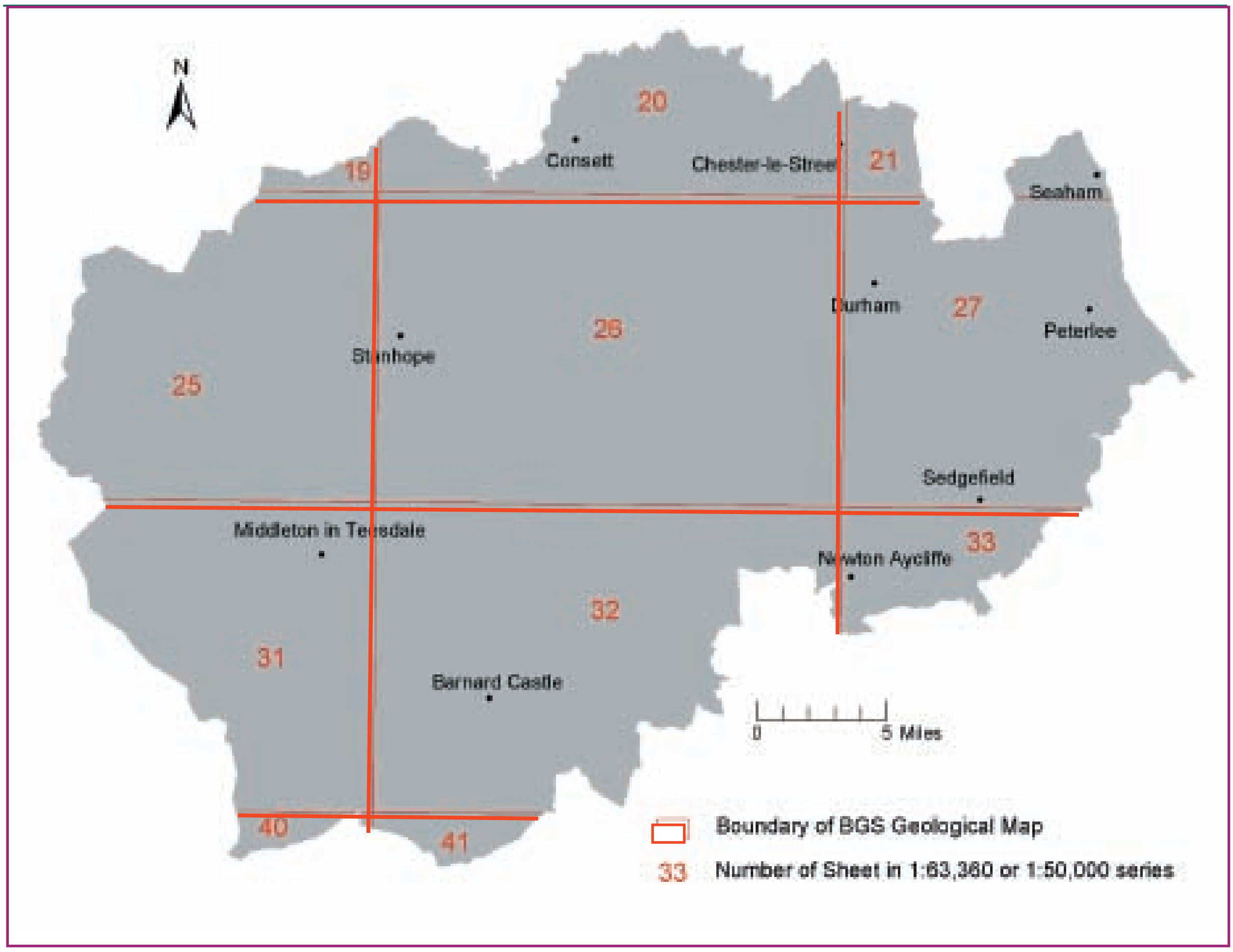


Figure 28. Index to BGS medium-scale geological maps in County Durham

1:50 000 scale

Sheet 19, Hexham, Solid geology, 1975

Sheet 20, Newcastle upon Tyne, Solid and drift, 1992; Solid with drift, 1989

Sheet 21, Sunderland, Solid, Drift, 1978

Sheet 25, Alston, Solid and drift, 1973

Sheet 26, Wolsingham, Solid and drift, 1977; Solid with drift, 1977

Sheet 27, Durham, Solid with drift, 1992

Sheet 31, Brough under Stainmore, Solid and drift, 1974; Solid with drift, 1974

Sheet 40, Kirkby Stephen, Solid and drift, 1997 [Provisional edition]

Sheet 41, Richmond, Solid and drift, 1997 [Provisional edition]

Medium Scale Geological maps are produced in a variety of styles, appropriate to the area concerned.

'Solid' maps show only the solid (bedrock) geology in colour. Drift deposits may be omitted or shown only as uncoloured areas indicated by pecked lines; small drift areas may not be indicated.

'Solid and drift' maps show both the solid and the drift geology, merged to represent the surface geology. Geological lines and symbols for the surface outcrops of both solid and drift deposits are shown, but details of solid deposits that are overlain by drift are normally abridged.

'Solid with drift' maps also show the solid and drift geology; but the drift deposits are uncoloured or only have coloured outlines. The buried geological boundaries of the solid deposits occurring beneath the drift are shown in full.

Large Scale Geology Maps

1:10 000 and 1:10 560 scale

Details of the original geological surveys at these scales are listed on editions of the 1:50 000 or 1:63 360 scale geological sheets. Copies of the fair-drawn copies of earlier geological surveys may be consulted at BGS libraries at Edinburgh and Keyworth and at the BGS London Information Office in the Natural History Museum, South Kensington, London. Copies of these maps may be purchased directly from the British Geological Survey as black and white dyeline, Xerox or photographic copies.

Books and reports

BGS books, memoirs and reports relevant to County Durham are listed in the reference section.

County Durham lies within the Northern England area of the *British Regional Geology* series of publications (Taylor et al., 1971). This is currently out of print and a new edition is in preparation. Other aspects of the general geology can be found in *British Geological Survey Memoirs* for the following BGS 1:50 000 sheets:

Sheet 20, Newcastle upon Tyne, Gateshead and Consett (Mills and Holliday, 1998)

Sheet 21, Sunderland (Smith, 1994)

Sheet 27, Durham and West Hartlepool (Smith and Francis, 1967)

Sheet 31, Brough under Stainmore (Burgess and Holliday, 1979)

Sheet 32, Barnard Castle (Mills and Hull, 1976)

In addition, important descriptions of the county's geology are contained in the following two *British Geological Survey Economic Memoirs*

Geology of the Northern Pennine Orefield Vol. 1 Tyne to Stainmore (Second edition) (Dunham, 1990)

Geology of the Northern Pennine Orefield Vol. 2 Stainmore to Craven (Dunham and Wilson, 1985)

Further details of publications, data sources and information are available from the British Geological Survey can be accessed on the BGS Web Home Page at www.bgs.ac.uk or contact BGS at:

Murchison House, West Mains Road,
Edinburgh EH9 3LA
☎ 0131 667 1000

or

Kingsley Dunham Centre, Keyworth,
Nottingham NG12 5GG
☎ 0115 936 3100

Soil Survey

Specialised information on soil character, properties and classification for the AONB may be obtained from the publications of the Soil Survey of England and Wales, now the Soil Survey and Land Research Centre, www.silsoe.cranfield.ac.uk/nsri.

Other Documentary Sources

Information on geological Sites of Special Scientific Interest (SSSIs) within County Durham is held by English Nature. Details may be obtained from:

English Nature (Northumbria Team),
Stocksfield Hall, Stocksfield,
Northumberland NE43 7TN
☎ 01661 845500

Information on Durham County Geological Sites is held by Durham County Council.

Durham County Council, County Hall,
Durham DH1 5UQ
☎ 0191 383 4567

Information on other geologically significant sites within County Durham are held at the Hancock Museum, Newcastle upon Tyne.

The Hancock Museum, Barras Bridge,
Newcastle upon Tyne, NE2 4PT
☎ 0191 222 6765

Mine Plans

Centuries of metal mining in the county have produced a substantial legacy of mine plans and related records. These documents, which contain huge amounts of often unique geological information, are an important element in the area's geological heritage.

At present there is no central repository of mining information, for minerals other than coal, in the UK. Large and important collections of such records are known to be cared for by a number of organisations, though many original, and thus unique, mine plans and associated documents are known to be in private hands. These are often difficult or impossible to trace. Plans are unknown for many mines, even where they are believed to have been maintained during the life of the mine. Many plans are known to have been lost or destroyed.

The County Record Offices of Cumbria, Durham, Northumberland and North Yorkshire have the most significant collections of mining information relating to the north of England. Other bodies holding mine records are the North of England Institute of Mining and Mechanical Engineers, based in Newcastle, the Edinburgh office of the British Geological Survey, The Coal Authority and Beamish Museum.

MATERIALS COLLECTIONS

Included here are significant collections of geological specimens. Although these are mostly museum collections, important material is also held by BGS and Durham University. Significant private collections of geological materials, mainly minerals, from County Durham have not been identified or evaluated in this study.

Museums and visitor centres all play a vital role in helping people to understand and enjoy earth science. There is considerable potential, with appropriate financial support, for local facilities to further expand their role in the provision of interpretation and education.

National Museums

Many specimens of rocks, minerals and fossils, collected within the county are held in the collections of Britain's national museums. These specimens, and their accompanying locality and other data, comprise an extremely important aspect of the county's geodiversity. This is especially important for material collected from sites which are no longer accessible and for which these specimens now offer the only means of study and research.

Very brief summaries are given here of the holdings of geological materials relevant to County Durham at each of these institutions. Contact details are also given to obtain further information, or to arrange access to the collections.

The Natural History Museum (formerly known as The British Museum (Natural History)

Cromwell Road, South Kensington, London
SW7 5BD, ☎ 0207 942 5000

Department of Mineralogy

The collection includes around 1000 registered mineral specimens from the mineral deposits of the Northern Pennines and adjoining parts of the Durham Coalfield, including exceptional specimens of all the major mineral species known in the area. Especially notable are specimens within the Russell Collection, particularly specimens of Northern Pennine fluorite.

Within its petrographical collections the department also holds specimens of representative rock types and rocks of economic importance, particularly building stones.

Contact for mineralogical collections:
Peter Tandy ☎ 0207 942 5076 (direct line)

Contact for petrographical collections:
Dave Smith ☎ 0207 942 5163 (direct line)

Department of Palaeontology

The palaeontology collections include many significant specimens from County Durham. Of particular significance are holdings of Carboniferous non-marine bivalves, notable examples of 'Frosterley Marble', including specimens of algae collected from this bed, Coal Measures plants and invertebrate and vertebrate fossils from the Permian rocks of eastern County Durham.

Contact for palaeontology collections: Paul Ensom, Head of Curation, ☎ 0207 942 5195
Email: P.Ensom@nhm.ac.uk

Royal Museum of Scotland

Chambers Street, Edinburgh EH1 1JF
☎ 0131 225 7534

Department of Geology

The mineral collection includes significant holdings of Northern Pennine minerals, including some notable specimens of alstonite, barytocalcite and witherite.

The palaeontological collections include Carboniferous and Permian fossils.

Contact for mineral collections: Brian Jackson
☎ 0131 247 4287 (direct line)

Contact for palaeontological collections:
Lyell Anderson ☎ 0131 247 4056 (direct line)

National Museum of Wales

Cathays Park, Cardiff CF1 3NP
☎ 02920 573281

Department of Geology

The museum has significant holdings of Northern Pennine minerals. Of particular importance are the well-documented specimens in the R J King collection.

Contact for geological collections: Jana Horak
☎ 02920 397951 (direct line)
Email: jana.horak@nmgw.ac.uk

Regional Museums

Specimens of geological material from County Durham are present in many museums throughout Great Britain. In many instances the material, though interesting, is not especially noteworthy and it is not feasible here to explore the scope of all such collections. However, the following regional and university museums have significant holdings of County Durham material.

Hunterian Museum, University of Glasgow

University Avenue, Glasgow G12 8TQ
☎ 0141 330 4221

The geological collections include a number of fine Northern Pennine minerals.

Contact for geological collections: John Faithful
☎ 0141 330 4221 (switchboard)
Email: j.faithfull@museum.gla.ac.uk

Manchester University Museum

Oxford Road, Manchester M13 9PL
☎ 0161 275 2634

Significant collections of Northern Pennine minerals, including notable specimens in the Harwood Collection, and important material collected in recent years from working mines in Weardale.

The museum also holds important collections of Lower Carboniferous corals and non-marine bivalves.

Contact for geological collections: Dr David Green Email: d.i.green@btinternet.com

Oxford University Museum

Parks Road, Oxford OX1 3PW

☎ 01865 272950

The geological collections include over 1000 mineral specimens from the Northern Pennines. These come mainly from a number of 19th or early 20th century collections, and from the Morrison Thomas Collection assembled during the early 1970s.

Contact for mineral collections: Monica Price

☎ 01865 272967 (direct line)

Email: monic.price@oum.ox.ac.uk

Contact for palaeontological collections:

Paul Jeffreys ☎ 01865 282454 (direct line)

Sedgwick Museum

University of Cambridge, Downing Street, Cambridge ☎ 01223 333 456

The geological collections include significant holdings of representative rock, mineral and fossil specimens.

Contact for geological collections: Mike Dorling, Head of Collections ☎ 01223 333456

Tullie House Museum

Castle Street, Carlisle CA3 8TP

☎ 01228 534781

Significant holdings of Northern Pennine minerals.

Contact for geological collections: Steven Hewitt

☎ 01228 534781 (extn 248)

Email: steveh@carlisle-city.gov.uk

Hancock Museum

Barras Bridge, Newcastle upon Tyne NE2 4PT

☎ 0191 222 6765

An important regional museum with significant holdings of minerals from the Northern Pennines, vertebrate fossils from the Permian rocks of eastern County Durham, and Carboniferous plant fossils from County Durham

Contact for geological collections:

Steve McLean ☎ 0191 222 6765

Sunderland Museum and Art Gallery

Borough Road, Sunderland SR1 1RE

☎ 0191 514 1235

An important regional museum with significant holdings of vertebrate and invertebrate fossils and rocks from the Permian rocks of eastern County Durham. The collections also include significant holdings of Carboniferous fossils from County Durham and minerals from the Northern Pennines.

Contact for geological collections:

Steve MacLean ☎ 0191 222 6765

Dorman Museum

Linthorpe Road, Middlesborough TS5 6LA

☎ 01642 813781

The geological collections include representative examples of North of England rocks, minerals and fossils, including significant holdings of Northern Pennine minerals.

Contact for geological collections: Ken Sedman

☎ 01642 813781 (switchboard)

Beamish, The North of England Open Air Museum

Beamish, County Durham, DH9 0RG

An important regional museum concerned with the cultural and industrial history of Northern England. The collections include objects, photographs and other archival documents relating to mining and quarrying. The site features public access and interpretation of underground coal workings in a small drift mine.

Visitor Enquiries and Main Switchboard:

☎ 0191 370 4000

Email: museum@beamish.org.uk

Killhope Lead Mining Museum

Near Cowshill, Upper Weardale, Bishop Auckland, Co Durham DL13 1AR

The museum holds a small collection of fine Northern Pennine minerals, a selection of which are on permanent display. The museum also houses the National collection of spar boxes.

Contact: Ian Forbes, Manager
☎ 01388 537505

Weardale Museum, Ireshopeburn, Weardale

The museum holds a small collection of minerals assembled by the late J Proud, a fluorspar miner at the nearby Blackdene Mine, and a small collection of fossils from Harthope Ganister Quarries, St John's Chapel, assembled by the late J Robson of Cowshill.

Contact: David Heatherington, Windyside, Westgate, Weardale, Co Durham DL13

Other Significant Collections

University of Durham – Department of Geological Sciences,

Science Laboratories, South Road, Durham DL1 3LE ☎ 0191 334 2000

The Department has no public displays of geological material, though its collections include specimens of Northern Pennine rocks, minerals and fossils.

In addition, the Department holds the bulk of the core from the Rookhope Borehole. This is currently housed in a building in Rookhope village.

Contact: Professor Jon Davidson, Head of Department ☎ 0191 334 2000 (switchboard)

British Geological Survey Collections

Borehole core samples

BGS holds rock and fossil specimens from a very large number of boreholes within the county. The collection includes a continuous slice of the Rookhope Borehole core.

Petrological collections

Thin sections of rocks from the county are registered in the British Geological Survey sliced rock collection. Most of these are of igneous rocks.

Palaeontological collections

Collections of fossil specimens, taken from surface, temporary exposures and boreholes throughout the county are registered in the British Geological Survey biostratigraphical collections.

For further information on BGS collections contact:

Murchison House, West Mains Road,
Edinburgh EH9 3LA
☎ 0131 667 1000

or

Kingsley Dunham Centre, Keyworth,
Nottingham NG12 5GG
☎ 0115 936 3100

GEOLOGICAL MODELS

Geological models are three-dimensional representations, often in simplified form, which have been used to illustrate or demonstrate a variety of geological structures or features. They may therefore be useful educational aids, or essential tools in mine planning. They may be constructed from a variety of materials.

It was common practice, until the advent of sophisticated computer graphics, to construct such models, during planning of mine exploration and development, to assist in visualising geological structures and their complex relationships. Modern computerised imagery enables the construction and manipulation of three-dimensional images without the need to construct physical models.

Geological models and geodiversity

Where such models illustrate specific features they provide a clear means of understanding the true three-dimensional nature of, often rather complex, features or structures.

Models, including those which illustrate the structural and stratigraphical relationships of mine workings, may represent important evidence for features which, though of great scientific significance, may no longer be accessible for study. As aids to the understanding of such features the models themselves may be legitimately regarded as important facets of geodiversity.

Geological models in County Durham

Two important types of geological models exist within County Durham.

Sopwith's models

The 19th century mine agent, and influential pioneer of geological thinking within the Northern Pennines, Thomas Sopwith (1803-1879) produced a number of wooden models to illustrate key geological structures encountered during mining and mineral exploration. A cabinet maker by training, Sopwith produced a number of these models using skilfully carved inlaid and layered combinations of different coloured woods. It is believed that between twenty and thirty sets of these models were made. They were highly regarded and were sold widely beyond the Northern Pennines, though examples are rarely seen today.

Photo 88. Thomas Sopwith with a selection of his wooden models of geological structures.

Killhope Lead mining Museum holds what is believed to be the only set of 'Sopwith models' housed today in County Durham. The set is an especially fine one, including the original explanatory notes sold with the models.

Mine models

Before the advent of three-dimensional computer graphics, it was the practice of some mine operators to construct models of their underground workings, to enable geologists and mine engineers to plan mine exploration and development. During the 1960s and 1970s, in the Northern Pennines, the British steel Corporation employed such models to visualise their underground developments at their fluorspar mines. The models were constructed from metal rods, coloured to depict stratigraphical horizon, vein intersections etc. They were built, and kept up to date, by professional model makers working in conjunction with the working plans of the mines.

The models of parts of the workings at Blackdene Mine, Weardale, and Beaumont (Allenheads, Northumberland) Mine, Allenheads, survive.

The **Blackdene Mine** model, the only one which relates to County Durham, is on display at the Weardale Museum, Ireshopeburn, Weardale. It is generally sound condition, though could benefit from some comparatively minor restoration, mainly to its paintwork. As it is currently displayed, the model is accompanied by some very brief explanatory notes, though there is no detailed interpretation.

The importance of these geological models spans the interests of geology, mining history and the development of geological understanding of the North of England.

SPAR BOXES

Spar boxes are cabinets lined with crystals of minerals found in the lead mines of the Pennine dales. They may be small cabinets less than a metre across, or in some instances, may measure several metres across.

Some spar boxes are comparatively simple and comprise a small cabinet lined with colourful crystals selected purely for their aesthetic effect. More elaborate spar boxes incorporated mirrors, models of mining or architectural features, and in some instances, a number of lighting effects. Many spar boxes incorporated stuffed and mounted birds, in addition to minerals.

Photo 89. Spar Box made with Northern Pennines and Cumbrian minerals.

A number of 'spar models' or 'spar towers' are also known. These consist of assemblages of selected crystals mounted in the form of a tower or mound and commonly covered by a bell jar.

The tradition of making spar boxes by miners seems to have been restricted to the lead mining areas of the Northern Pennines, the Isle of Man and the iron mining areas of west Cumbria. There is no evidence of spar box making in other UK mining areas.

Fluorite, in various colours is usually a major component, of Northern Pennines spar boxes accompanied by quartz, calcite and commonly examples of ore minerals including galena. Barium minerals seem not to have been favoured by spar box makers. An interesting feature of many Northern Pennine spar boxes is the inclusion within them of minerals clearly identifiable as being derived from the west Cumbrian iron ore field. These include striking examples of aragonite, calcite and haematite in a number of forms. It seems that some form of trade, or exchange, of specimens was routinely practiced by miners and spar box makers.

Spar boxes and geodiversity

Although spar box making cannot be seen as a form of systematic collecting and curation of mineral specimens as scientific objects, it is an extremely important facet of the local mining tradition. Surviving spar boxes represent both an interesting resource of, often high quality though generally poorly localised, mineral specimens and an important legacy of a tradition almost unique to this mining field.

Spar boxes may be seen as interesting and almost unique aspects of the county's mineralogical heritage, and provide a superb opportunity to link the appreciation and understanding of earth science with an unusual rural craft tradition.

Spar boxes were once commonplace items of domestic decoration in many west Durham dales cottages. With the passage of many years since the demise of widespread lead mining, and the increasing interest and associated commercial value placed upon mineral specimens, spar boxes have attracted the attention of dealers and collectors. Many have been sold to collectors and dealers outside the county.

Killhope, the North of England Lead Mining Museum displays the National Collection of spar boxes, including the famous Egglestone Spar Box, built in 1904, and believed to be the largest ever made.

COLLECTING OF GEOLOGICAL MATERIALS

Rocks minerals and fossils are collected for very many reasons.

They may be picked up as curiosities. Such casual collecting typically lacks any purpose and generally has little impact upon the resource.

More focussed collecting commonly forms part of a range of educational activities, from infant school to university level. Many forms of earth science research require the collecting of material for specialised study or analysis in the laboratory. Such collecting is highly focussed.

Recreational collecting of particular geological materials is popular with many individuals and groups. Whereas some of this collecting may form part of an individual or group interest in gaining greater understanding of those geological materials, and the processes involved in their formation and evolution, much collecting lacks any such underlying purpose.

Collections of rock, mineral and fossil specimens have, over the years, been assembled by a wide variety of collectors including both trained earth scientists and amateur collectors with no formal scientific training. In considering collections of earth science materials the vital role of the latter group of collectors should not be underestimated. Many of the world's finest collections owe much to their efforts, particularly their role in recovering material which would otherwise have been destroyed during mining or quarrying operations. Recreational collecting, particularly of minerals and fossils, remains a popular leisure activity in Britain today.

Once any object becomes 'collectible' it almost invariably assumes a commercial value. This is as true of geological materials as it is of coins or fine paintings. Commercial collecting of minerals and fossils pre-dates the emergence of earth science. Such commercial collectors and dealers have played, and still continue to play, a vital part in forming the great collections of geological materials.

Collecting and geodiversity

As in all branches of natural history, collecting has figured prominently in geology, both as an essential part of research and as a recreational pursuit. Without well-curated collections of geological materials, many avenues of geological investigation would be impossible. Collecting and collections are essential facets of geodiversity.

Collecting in County Durham

Almost all geological materials within the county are, or have been, the target of some form of collecting.

However, two main areas of geological science within the county attract interest, particularly from recreational collectors. The mineral deposits of the Northern Pennines, and the spectacular and unusual minerals they contain have long been a major focus of collecting interest. Rather more recently, a comparatively small number of collectors have been attracted to the vertebrate fossils found within the Permian Marl Slate.

Positive aspects of collecting

There have been many very positive and beneficial aspects to collecting.

Within County Durham, generations of Northern Pennine miners have recovered attractive or colourful examples of minerals encountered in the workings. These 'bonny bits' were used to decorate homes and gardens, or found their way into 'spar boxes', a craft that seems to have been almost unique to the Northern Pennines and West Cumbria and comprises another facet of the county's rich geodiversity (*see Spar Boxes*). The sale of specimens to mineral dealers was on occasions an important additional source of income to many miners. By this route many significant specimens found their way into important museum collections. Without such collecting and commercial trading in the materials collected, the world's museum collections would be much the poorer.

Like their counterparts in the county's lead and fluorspar mines, coal miners and quarrymen were commonly attracted by interesting material encountered in their workings. Numerous fossils of Coal Measures plants, invertebrates and much rarer vertebrate remains found their way into permanent collections through such activities. Particularly important are the large collections of Permian invertebrates and vertebrates collected over many decades by a variety of collectors, many of them with no formal scientific training. The large and important collections of these materials held today by local and national museums, bear eloquent testimony to the continuing heritage and research value of such collecting.

In common with many parts of Great Britain, many features of the county's geology are today inaccessible and can be understood only from the scientific literature or from suites of specimens preserved within significant geological collections. These comprise an extremely important part of the area's geodiversity.

Important geological materials still come to light during quarrying operations and other activities such as construction or road making which may reveal temporary exposures of geological features. In most instances such materials are almost inevitably destined for destruction unless recovered by some form of collecting. Similarly, in some circumstances collecting from abandoned underground mines may recover material that might otherwise be irretrievably lost when the workings eventually become inaccessible. Recovery of such material, if undertaken with appropriate scientific rigour and if accompanied by the making of appropriate records, can make important contributions to understanding of geodiversity.

The negative aspects of collecting

At the time of writing, unauthorised collecting of minerals from underground workings and surface exposures is known to be being pursued at several localities. The collectors involved generally have little or no geological training and, in most instances it is known that little or no attempt is being made to record features of geological interest or significance.

In consequence, it is likely that irreplaceable features, which exhibit important *in situ* relationships, of great geological significance will almost certainly be lost.

There is evidence that mineral collecting has seriously depleted, or in some cases exhausted, the accessible resources of several mine spoil heaps and damaged some exposures of mineralisation. Whereas some of the specimens collected have found their way into research organisations or public collections, in many instances few, if any, meaningful records of the occurrences have been made.

Collecting from several such sites is known to have been motivated primarily by the pursuit of saleable specimens. This inevitably means that aesthetic considerations are paramount in the preservation of the material: unattractive or unsaleable material is typically destroyed in during such activities. As specimens of great scientific interest may be aesthetically unappealing, much important material has thus been lost.

Some forms of collecting have therefore certainly caused serious damage to the area's geodiversity.

Controls on collecting in County Durham

These are currently very limited. Removal of geological materials from a site without the consent of the legal owner of the geological material may constitute theft. The obtaining of permission from the appropriate land or quarry owner is usually sufficient to resolve this legal aspect, though the legal owner of the geological feature and the materials within it may be unaware of their importance or fragility. Several landowners impose restrictions on collecting when granting access to their land, in some instances forbidding all collecting. In remote upland parts of the county, where ownership is often difficult to establish, much collecting is undertaken without any form of consent from the owner of the geological materials. There is no effective control in such cases.

Sites which are scheduled in some way, e.g. as SSSIs, SAMs, may have restrictions on collecting embedded within their management agreements.

English Nature publish best practice guidelines on fossil collecting, and guidelines on mineral collecting are in preparation.

A Code of Conduct for Geological Fieldwork, compiled by the Geologists' Association, has long been adopted by most professional earth scientists, educational and research establishments, and the more responsible geological societies. However, a significant number of individual collectors, and some societies, appear to be unaware of, or ignore, this code.

Collecting for education and research

An element of collecting, whether the assembling of a systematic collection or the casual removal of rock fragments during a field excursion, remains an important facet of education in the earth sciences. It is simply not possible to train as a geologist without having the ability to handle and gain a feeling for, as wide a variety of geological materials as possible in the field. The collecting of rocks, minerals or fossils, by youthful collectors is often the first step to an interest, or even career, in the earth sciences.

The area remains an important focus of research in the earth sciences. There will therefore remain an important requirement for the continued structured and disciplined collection of geological materials.

Several areas, or sites, could be identified which might be suitable for use by educational parties. These would need to be negotiated with landowners.

Quarries may be willing to set aside stockpiles of material suitable for educational, or recreational use, including collecting, in safe areas of their property. This material may well be waste or overburden material. Some quarries are understood to be making such provision for controlled collecting.

Selected references

English Nature, 2000, 2003; Hacker, 2003.

GEOLOGICAL SOCIETIES

Locally-based geological societies

The following geological societies are active within northern England:

Natural History Society of Northumbria (Geology Section)

North East Geological Society

Open University Geological Society (NE Branch)

Russell Society (Northern Branch)

Yorkshire Geological Society

Although not a geological society, the **Friends of Killhope** organises events, some of which involve aspects of the area's geology.

All of these societies arrange programmes of lectures and field meetings, several of which relate to aspects of the geology of County Durham.

The Annual Mineralogical Exhibition, organised by the Friends of Killhope, provides a unique opportunity to see examples of some of the area's finest minerals.

The county's very substantial geological interest and importance attracts groups from many other parts of Great Britain and abroad. There is, however, currently no means of monitoring this level of use.

Contribution by societies to geodiversity in County Durham

Geological societies perform an important role in communicating relevant knowledge and expertise both to their members and the wider public.

Several societies publish journals and newsletters in which original observations, or reviews, of local geology are reported.

Especially noteworthy are the many original papers which have appeared over many years in the *Proceedings of the Yorkshire Geological Society* and *The Transactions of the Natural History Society of Northumbria* (formerly the Natural History Society of Northumberland, Durham and Newcastle upon Tyne).

Most of these societies have contributed information and comments during the compilation of this Geodiversity Audit. Local geological societies may have a useful role in the future monitoring and review of geodiversity issues within the County.

With the designation of the Northern Pennines AONB as a European Geopark there is very substantial scope for increased involvement of such societies, particularly in events and initiatives which may be organised through the AONB Partnership.

There is currently no 'Rock Watch Group' active within, or close to County Durham. There is considerable scope to encourage the establishment of such a group to attract youngsters interested in the area's natural heritage.

INTERPRETING EARTH SCIENCE WITHIN COUNTY DURHAM

Geological interpretation embraces all methods of communicating information on aspects of earth science to specialist and non-specialist audiences alike.

Describing and interpreting the nature and importance of earth science features is an important aspect of the county's geodiversity. Well-planned earth science interpretation not only highlights the importance and relevance of geological interest, but also has enormous potential to contribute to, and enhance, the understanding of features and sites of parallel interest including the area's ecological habitats, many of the historic buildings and some historical mine sites. Thus, the understanding of, for example, a limestone grassland, a population of metallophyte plants, or the features visible at a mining site can be greatly enhanced if the geological factors responsible for these are explained in an appropriate context.

A substantial portion of the west of the county lies within the North Pennines European Geopark. High quality and well-planned earth science interpretation is a vital function of a European Geopark.

Photo 90. Interpretation panel. West Rigg Opencut, Westgate, Weardale.

Target audiences for earth science interpretation in County Durham

Earth science interpretation is relevant to a very wide spectrum of interests. The following main end-users may be recognised, though the list is neither exhaustive nor mutually exclusive:

Specialist earth scientists

Professional specialists in fields other than earth science

Educational users, including school groups at every level, and higher educational groups

Specialist recreational users, such as members of special interest societies

The general public, including residents and visitors

Requirements of target audiences

Specialist earth scientists

As with all specialist fields, a wide range of avenues exist for communicating the results of original survey and research findings in earth science through scientific journals and other publications. Such information is generally of a very technical nature and aimed at a clearly identifiable and specialised audience or readership.

Specialists in fields other than earth science

Many practitioners in a number of specialist fields recognise a requirement for relevant earth science information as a means of informing or enhancing work in these fields. However, great scope exists to expand the inclusion of such relevant earth science information. Vital to the employment of earth science information is its presentation in a form comprehensible and relevant to the needs of such users.

Educational users, including school groups at every level, and higher educational groups, teachers and lecturers

Relevant information in a form accessible to the needs and abilities of both the students and teachers is needed.

Earth science offers excellent opportunities to engage the curiosity of children in the natural world and to use this as a means of introducing them to the wider concepts of natural science. Many children develop a fascination with fossils and minerals and may be extremely receptive to gaining some understanding of geological materials and processes. Provision of suitable publications, displays and specially planned events are all means of harnessing this enthusiasm. The 'Rock Watch' scheme operated by the Geologists' Association has been extremely successful in this field in other parts of Great Britain. The scheme currently has little representation in County Durham or most of its immediately surrounding areas, though attempts could be made to encourage its growth here.

Specialist recreational users, such as members of special interest societies

The requirements are very similar to those of educational groups, though greater emphasis perhaps needs to be directed to understanding those topics which are likely to be of greatest interest, and to appreciating the very varied levels of technical understanding of the groups involved.

The general public, including residents and visitors

A substantial proportion of the area's residents have a strong sense of regional identity and a significant level of understanding of the natural heritage of their home area. With its long tradition of extractive industries, the important role of rocks and minerals in the natural, historical and cultural heritage of the county is already recognised, though this not generally fully understood and interpretation is limited.

County Durham attracts many visitors on a daily or longer-term basis. Most are attracted by aspects of the natural or cultural landscape. Many are attracted by the historical legacy of the former mining industries.

Residents and visitors represent a very substantial pool of interest for explanation and interpretation of those natural features of the area which give it its distinctiveness and which have been at the heart of the area's historical development. A very substantial audience exists for clear and authoritative, though non-technical and accessible interpretation.

Delivery of earth science interpretation

Detailed technical descriptions and interpretations, targeted at specialist earth scientists, are delivered through a variety of scientific journals, publications etc.

Photo 91. Interpreting lead mining at Killhope Lead Mining Museum.

Communication of appropriate technical earth science information to specialist workers in fields other than earth science currently relies very much upon those specialists being able to access and interpret a range of specialist literature. The establishment of working relationships between earth scientists and other specialists is a fruitful means of enhancing such work. Very considerable scope exists to further encourage and build closer working relationships between earth scientists and other specialists.

Interpretation to educational groups can be delivered through specially prepared literature, booklets, worksheets etc. Classes, workshop sessions, field excursions etc. organised and run by, or in association with, relevant experts and local visitor or educational centres can be tailored to all educational levels. Input of professional expertise, or collaboration with, sections of the extractive industries, e.g. through quarry visits, talks etc. delivered by industry staff or representatives, can be extremely effective.

A variety of interpretation methods, aimed at all levels of interest and ability, can be employed at visitor centres. These may include interpreted displays of geological materials e.g. rocks, fossil or mineral specimens, borehole cores etc., maps, diagrams and geological models, a variety of interactive displays and 'hands on' interpretation.

Classes and 'day schools' built around one or more geological themes, and involving relevant experts, can be highly successful.

Local community groups with interests in natural history, archaeology, heritage etc. may be instrumental in identifying and initiating locally based interpretation projects, in collaboration with suitable expert advice and assistance.

Guided tours or walks can be organised, either by local authorities, visitor centres, or various interest groups, perhaps involving public participation in specialist society activities.

Display panels explaining key aspects of geological features, 'on the ground', can be extremely useful.

Interpretation leaflets, geological trail leaflets, thematic booklets and books all offer excellent, and potentially commercially viable, means of delivering high quality interpretation.

Current earth science interpretation in County Durham

Visitor centres

Earth science interpretation relevant to County Durham is currently available at Killhope Lead Mining Museum, Weardale and the Dales Centre, Stanhope. Small displays of geological materials relevant to the county, though without significant interpretation, may be seen at the Weardale Museum, Ireshopeburn and Bowlees Visitor Centre, Teesdale.

On-site interpretation panels

On-site panels provide interpretation of a variety of features throughout the county. Erected at various dates, by various organisations, and today in varying condition, a very small number of these include some element of earth science interpretation, though at only a handful of sites, e.g. West Rigg in Weardale, Stanhope Church Yard in Weardale, Cow Green in Teesdale, and at a few sites on the Durham coast is the earth science interest the principle focus of the interpretation.

Interpretation leaflets

Specially designed leaflets which explain the geological features visible at two sites have been produced by Durham County Council as part of a new series style Geotales of the North Pennines.

Titles so far published are:
Old Moss Vein, Weardale
Slitt Wood & West Rigg, Weardale

Leaflets produced by English Nature for the Moorhouse - Upper Teesdale National Nature Reserve include some elementary geology.

A new leaflet, and accompanying on site interpretation material, is in preparation by English Nature for the Castle Eden Dene National Nature Reserve.

These leaflets draw attention to the important links between the geology and the ecology of the area.

Guided walks

The annual programme of guided walks run by the County Council, usually includes a few walks in which aspects of geology and landscape are interpreted at an elementary level.

GLOSSARY

Adit	Horizontal, or nearly horizontal, tunnel or mine entrance
Alluvial	Sediments, which may be gravel, sand, silt or mud, which have been transported and deposited by rivers
Ammonoid	A subclass of molluscs with coiled shells belonging to the class Cephalopoda
Anticline	Arch-shaped fold of rocks, closing upwards
Argillaceous rocks	Sedimentary rocks composed of of very fine grain silt or clay-sized particles (<0.0625 mm), usually with a high content of clay minerals
Armour-Stone	Large stone block used in coastal defence and other engineering works
Aureole	Area surrounding an igneous intrusion affected by metamorphic changes
Basalt	A dark-coloured, fine-grained, usually extrusive, igneous rock composed of minerals rich in iron and magnesium and with a relatively low silica content
Batholith	A large body of intrusive igneous rock with no visible floor
Biostrome	A layered, sheet-like *in situ* accumulation of organisms
Bituminous	Rich in hydrocarbons or bitumen
Bivalve	A class of molluscs with paired shell valves
Blanket Bog	An extensive area of peat bog
Bouguer Anomaly	A gravity anomaly calculated after corrections for latitude, elevation and terrain.
Brachiopod	A phylum of solitary marine shelled invertebrates
Braided Rivers	A river consisting of a number of small channels separated by bars
Breccia	Coarse-grained clastic sedimentary rock consisting of angular fragments of pre-existing rocks
Breccio-conglomerate	A rock composed of both angular and rounded fragments of pre-existing rocks. It is intermediate in character between a breccia and a conglomerate
Brockram	A term used in NW England for breccias and conglomerates of Permo-Triassic age
Bryozoa	A phylum of small aquatic colonial animals
Calc-silicate	A group of minerals consisting of calcium silicates
Chert	A dense, microcrystalline form of silica which occurs as nodules or beds within parts of the Carboniferous succession of rocks
Chronostratigraphy	The standard hierarchical definition of geological time units

Cleavage	A property of rocks such as slate, whereby they can be split into thin sheets along aligned fractures or planes produced by the pressures that affected the rocks during severe earth movements
Columnar jointing	The crudely polygonal system of vertical joints formed in response to cooling of bodies of intrusive igneous rocks such as sills and dykes
Conglomerate	Coarse-grained clastic sedimentary rock composed of rounded or sub-rounded fragments of pre-existing rocks
Continental shelf	The gently sloping offshore zone, extending usually to about 200 metres depth
Crinoid	Or 'sea lillies' are marine animals composed of calcareous plates, belonging to the phylum Echinodermata
Cross-bedding	Internally inclined layers in a rock related to the original direction of current flow
Cupola	A dome-shaped offshoot rising from the top of a major igneous intrusion
Desiccation cracks	Or shrinkage cracks are polygonal cracks formed in a sediment as it dries out in a terrestrial environment
Displacement	The relative movement on either side of a fault plane
Doline	Or sink hole, is a steep-sided enclosed depression in a limestone region
Dolomitic limestone	A limestone containing a high concentration of the mineral dolomite
Dolomitisation	The process by which limestones are wholly or partially transformed into dolomite
Dry valley	A valley produced by running water but which is presently streamless
Dyke	Discordant, sheet-like bodies of intrusive igneous rock in a vertical, or near-vertical orientation
Evaporites	Sedimentary deposit of minerals formed by natural evaporation
Fault	A fracture in rocks along which some displacement has taken place
Feldspar	A group of rock-forming minerals consisting of silicates of aluminium, sodium, potassium, calcium and more rarely barium
Felsite	A general term used to denote fine-grained acid or feldspar-rich igneous rocks
Fissile	The tendency of a rock, such as a shale or slate, to split readily into thin sheets along closely spaced bedding or cleavage planes
Gangue	Generally valueless mineral or rock which accompanies an ore
Gastropod	Molluscs belonging to the class Gastropoda, usually with coiled shells
Gouge	Broken rock, often shale or clay, in a mineral vein or between fault planes

Graptolite	A group of extinct colonial marine organisms. Generally placed in the phylum Chordata, but sometimes regarded as Coelenterata. They consist of one or more branches or stipes in which individuals in the colony occur in rows
Greywackes	A sandstone containing a high proportion of silt, clay and rock fragments in addition to quartz grains
Hornfels	A fine-grained rock that has been partly or completely recrystallised by contact metamorphism
Hydrothermal	Processes involving hot ground waters. Includes the formation of mineral veins and the associated alteration of rocks in the formation of flat deposits
Inlier	An outcrop of older rocks surrounded by rocks of younger age
Joints	A fracture, or potential fracture, in a rock adjacent to which there has been no displacement
Lamprophyre	A group of intrusive igneous rocks characterised by abnormally high contents of silicate minerals such as biotite, hornblende and augite, with generally small amounts of feldspar
Lapilli-tuff	A compact rock composed of small pieces of lava or ash rounded during eruption
Lithified	Literally ‘changed to stone’. Applied to loose sediment which has been consolidated to a solid rock
Lithology	The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents
Magma	Molten rock
Magnetic anomaly	The value of the local magnetic field remaining after the subtraction of the dipole portion of the earth's field
Marl	An old term loosely applied to a variety of sediments which typically consist of intimate mixtures of clay and calcium carbonate
Metamorphism	Change in the mineralogy and structure of a rock as a result of the effects of heat and/or pressure
Millet seed grains	Smooth and conspicuously rounded sand grains which resemble millet seeds. Commonly with frosted surfaces resulting from wind action in desert environments.
Monocline	A one-limbed fold on either side of which the strata are horizontal or dip at only low angles
Mountain building	The complex series of geological processes which create mountains
Nunatak	An isolated mountain peak projecting from an ice sheet
Oolitic limestone	A limestone consisting predominantly of sub-spherical, sand-sized, concentric grains, or ooids, composed of calcite or dolomite

Ostracod	Small arthropods belonging to the subclass Ostracoda, having a twin shell
Outlier	A remnant of a younger rock surrounded by older strata
Palaeomagnetic	The magnetic characteristics of a rock formed in the geological past
Pegmatite	An igneous rock of especially coarse grain size
Phenocryst	Large crystals, usually of near perfect shape, embedded in a fine-grained matrix in igneous rocks
Phreatic	Volcanic eruptions generated by the interaction between hot magma and surface or ground water
Phyllites	A cleaved metamorphic rock characterised by a silky lustre due to minute flakes of white mica which are too small to be seen by the naked eye
Pisolitic limestone	A limestone consisting predominantly of sub-spherical, concentric grains larger than 2mm in diameter, or pisoliths, composed of calcite or dolomite
Porphyritic	The term applied to igneous rocks which contain isolated crystals, or phenocrysts, larger than those forming the main body of the rock
Pseudomorph	A secondary mineral, or a random aggregate of secondary minerals, which have replaced a pre-existing mineral, but have retained its shape
Radiometric dating	The method of determining the geological age by measuring the relative abundance of parent and daughter isotopes in rocks
Rendzina	A brown earth soil of humid or semi-arid grassland that has formed over calcareous parent material.
Ripple marks	Small scale ridges and troughs formed by the flow of water or wind over unconsolidated sandy or silty sediment. The fossilised equivalent of ripples found today on beaches and river sands
Rottenstone	Any highly decomposed but still coherent rock
Sedimentary rocks	Rocks formed by the accumulation of fragments from the wasting of previous rocks or organic materials, deposited as layers of sediment
Sill	A tabular igneous intrusion with concordant contacts with the surrounding wall rocks
Sink hole	See doline
Slate	A fine-grained metamorphic rock derived mainly from mudstone or shale, and which splits, or cleaves, readily into very thin sheets as result of the re-alignment of its constituent minerals during metamorphism
Statigraphy	The definition and description of the stratified rocks of the Earth's crust
Streak	The name given to the colour of the powder of a mineral or rock
Stromatolite	A laminated, mound-like structure, built up over long periods of time by successive layers or mats of algae or bacteria, which have trapped sedimentary material

Supergene	Alteration formed near the surface
Syncline	A concave-upwards fold with the youngest rocks in the centre
Syngenetic ore or mineral deposit	A deposit formed simultaneously with the host rock and by similar processes
Tailings	Fine-grained waste from mineral processing operations
Throw	The amount of displacement on a fault
Trilobite	Extinct marine arthropods characterised by having a segmented oval body divided into three segments
Tufa	A porous or cellular deposit of calcium carbonate deposited from lime-rich springs
Tuff	A rock formed of compacted volcanic fragments
Turbidity current	A dense sub-marine flow of mixed water and sediment, capable of very rapid movement
Unconformity	A substantial break in the succession of stratified sedimentary rocks following a period when no deposition was taking place
Volcaniclastic	A rock containing volcanic fragments in varying proportions
Xenolith	A foreign inclusion in an igneous rock

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