

Northumberland National Park Geodiversity Audit and Action Plan

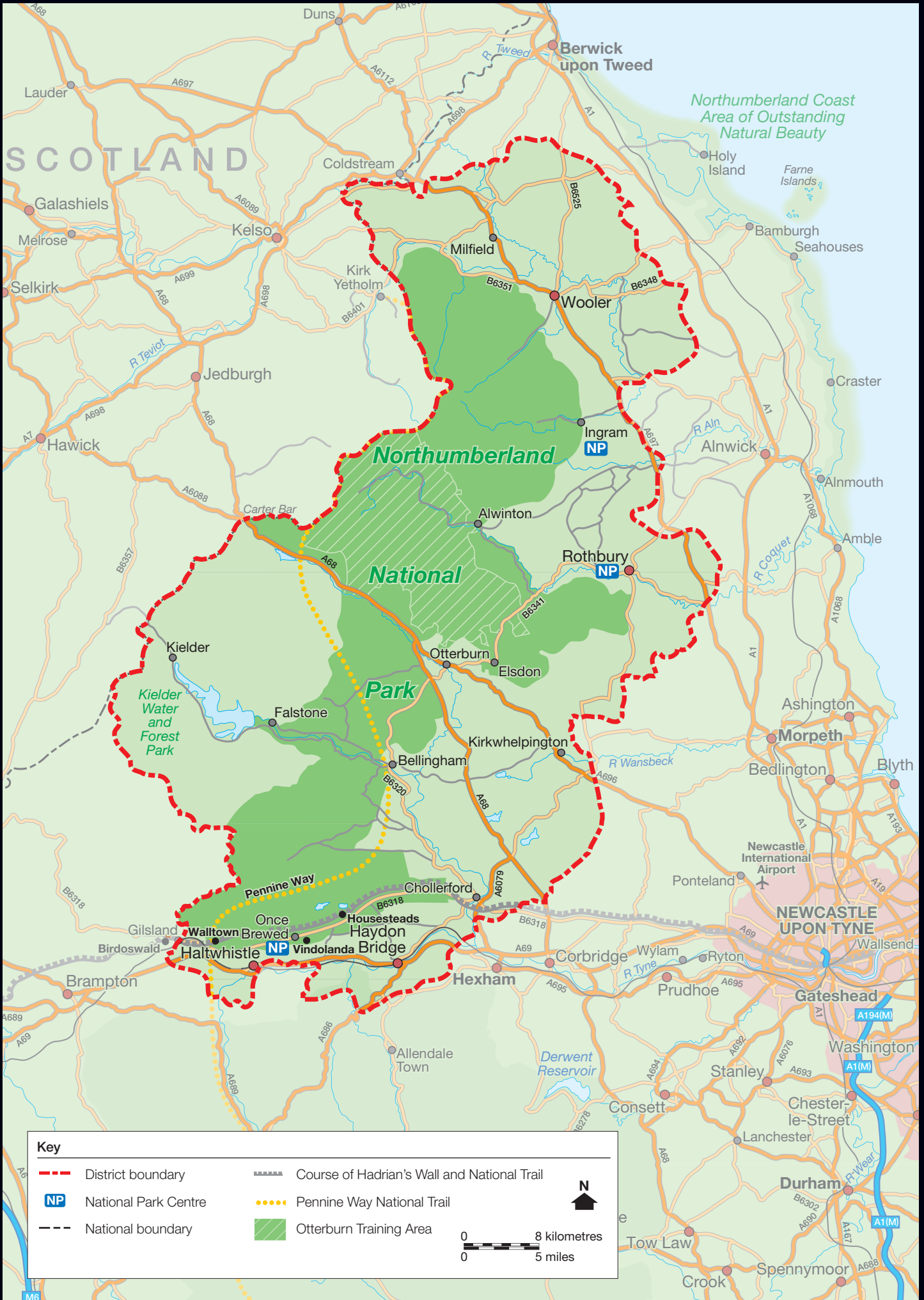


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL



Northumberland National Park

Location map for the district described in this book



Northumberland National Park

Geodiversity Audit and Action Plan

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Hadrian's Wall above cliffs of Whin Sill, looking west towards

Crag Lough © Graeme Peacock www.graeme-peacock.com

The Drake Stone, a huge Fell Sandstone boulder near Harbottle
BGS © NERC

Cawfields Quarry in the Whin Sill, now a recreation area

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Looking south-west from Long Crag towards the granite hills of

Hedgehope and Cheviot © Graeme Peacock www.graeme-peacock.com

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Northumberland National Park

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Foreword

The study and recommendations presented here represent the first attempt to address the varied facets of geodiversity within the Northumberland National Park and adjoining area, which for the purpose of this publication is called the *district*, shown on the inside front cover. Moreover, as the first comprehensive Geodiversity Audit and Action Plan prepared specifically for any of the 14 National Parks in Great Britain, it is hoped that this publication will serve as an example of good practice for other National Parks and protected areas. The importance of the rich natural and historical heritage and the need to ensure protection of this precious resource are fundamental to the sustainable management of the Northumberland National Park. Some aspect of earth science impacts upon almost every facet of the district's character. Policies for the better protection and understanding of wildlife, cultural and historical issues are already in place for the National Park. To these must be added policies designed to understand, protect and interpret the area's equally rich geodiversity. The Northumberland National Park Authority published its first Biodiversity Action Plan in 2000, since when it has been working in partnership with other agencies and land managers to achieve its objectives for biodiversity including seeking a more favourable conservation status for all the Park's habitats and species. It is anticipated that this Geodiversity Action Plan will similarly provide the impetus for increased protection and enhancement of geodiversity and encourage the involvement of the local community. Additionally, as we improve our understanding of the role that geodiversity plays within the wider environment, and its influence on our wildlife, we can help ensure a positive future for species and their habitats as they respond to a changing world.

Opposite: The distinctive skyline of the Fell Sandstone ridge at Simonside viewed from Rothbury Terraces
© Graeme Peacock www.graeme-peacock.com

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Opposite: Yeavinger Bell hill fort built on high ground formed by rocks of the Cheviot Volcanic Formation © Graeme Peacock www.graeme-peacock.com

Section I

Understanding geodiversity



What is geodiversity?

Geodiversity may be defined as the variety of rocks, fossils, minerals, natural processes, landforms and soils that underlie and determine the character of our landscape and environment. It is fundamental to almost every aspect of life. Britain's geodiversity is the bedrock of our environment, it is the source of much of our wealth, an important factor in our cultural identity, and will play a vital role in our future development. 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 disposal of waste, and the management of a wide range of natural and man-made hazards.

Geodiversity links people, landscape, biodiversity and culture, and is a vital natural resource. An appreciation of geodiversity is important to a full understanding of many aspects of biodiversity, in particular it has a profound influence on where habitats and species are found. It also has an important impact on the economic activities and history of settlement in any given place. It is fundamental to how our natural environment works and, consequently, to the way we live and work. The geodiversity of a region is as important a facet of its natural heritage as its wildlife interests and it can be one of the

most significant areas of heritage interest, especially in regions in areas of high landscape value, or those previously or currently affected by significant mineral extraction. Conservation, sustainable management, educational use and interpretation of geodiversity are thus as important as those of biodiversity or archaeology, and geodiversity interests need to be integrated into the management and conservation strategies for such related or parallel interests. Geodiversity issues may contribute significantly to informing a wide range of planning and environmental policies.

English Nature (now incorporated in Natural England) has been instrumental in advancing geodiversity and in encouraging strategic initiatives such as the preparation of Local Geodiversity Action Plans (LGAPs). A variety of their publications relating to geodiversity are listed in the bibliography (p. 126). BGS has been at the forefront of geodiversity studies in northern England and this Geodiversity Audit and Action Plan builds upon and complements work carried out in County Durham and the North Pennines Area of Outstanding Natural Beauty.

A fundamental starting point in understanding an area's geodiversity is an appreciation of the most up-to-date available knowledge of its geological deposits and features, together with the processes and phenomena that have formed them and continue to influence them.

An area's geodiversity includes

- The broad bio-geographical, geological and geomorphological character of the area
- Key natural systems and processes within the area, such as fluvial processes
- Main landscape features, including those which, due to their linear or continuous nature, are important for the migration, dispersal and genetic exchanges of plants and animals
- Sites where representative examples of the area's geological deposits and features may be seen
- Sites which are deemed worthy of some form of designation or protection for the quality of the 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. The inter-relationship and inter-dependence between earth science and other interests
- Materials collections and site and other records relating to the district
- Published literature and maps
- The historical legacy of research within the area

The scope of this Geodiversity Audit and Action Plan

This Audit and Action Plan is intended for all those interested in the geodiversity of Northumberland National Park and the surrounding area (called the district for the purpose of this publication) and seeks to address geodiversity in its very broadest sense. It is a collaboration between BGS, Northumberland National Park Authority and Natural England, and forms part of the MIRO-funded project *Implementing a sustainable geodiversity framework in an area of aggregate extraction – the Northumberland National Park and adjoining area*, which was designed to examine the geodiversity resource and identify ways of exploiting it within the co-ordinated framework of the National Park strategy. Although dealing with a varied, and sometimes complex, range of issues relating to earth heritage, it 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. This publication and associated GIS information will help to provide a strong environmental evidence base for adoption of good practice in the planning system. Additional details will be available as BGS internal publications complementary to this report.

It does not seek to offer a detailed geological description of the district, or provide detailed technical advice, but introduces those aspects of the geology that are essential to appreciating their importance in the district and beyond. The use of technical language has been kept to a minimum, though the use of some geological terms is unavoidable. To assist readers unfamiliar with such terms a glossary is provided.

National Parks

Britain's National Parks contain some of the nation's finest and most dramatic landscapes. The UK's 14 National Parks are part of a global family of 6555 protected areas, covering one million square kilometres or 12% of the Earth's surface. They are linked to Europe through the EUROPARC Federation – a network of European protected areas with 360 member organisations in 37 countries. In 1949, government passed an Act of Parliament to establish National Parks to preserve and enhance their natural beauty and provide recreational opportunities for the public. Lewis Silkin, Minister for Town and Country Planning, described it as "...the most exciting Act of the post-war Parliament."

Whittingham village with houses constructed of local sandstone, the Cheviots in the background



Each UK National Park is administered by its own National Park Authority. They are independent bodies funded by central government to:

- conserve and enhance the natural beauty, wildlife and cultural heritage; and
- promote opportunities for the understanding and enjoyment of the special qualities of National Parks by the public

In carrying out these aims, National Park Authorities are also required to seek to foster the economic and social well-being of local communities within the National Park.

Northumberland National Park

Northumberland National Park stretches from the Cheviot Hills on the Scottish border, to the spectacular central part of Hadrian's Wall in the south. It is a place of wild and sweeping landscapes, whose character is profoundly influenced by the underlying rocks and landforms. These seemingly wild and natural landscapes are also a product of human activity over time.

Northumberland National Park was designated in 1956 and since then work to achieve National Park purposes has been carried out by local government, first by Northumberland County Council and, since 1997, by the free-standing Northumberland National Park Authority. The Authority works with people and communities in and around the National Park to achieve its National Park Purposes and Vision:

"...Northumberland National Park Authority will be proactive, innovative and forward-looking, working towards a National Park with thriving communities and a sustainable local economy grounded in its special qualities, including a richness of cultural heritage and biodiversity, a true sense of tranquillity and a distinct character associated with a living, working landscape, in which everyone has an opportunity to understand, enjoy and contribute to those special qualities."

Through its four Action Areas – Hadrian's Wall, North Tyne and Redesdale, Coquetdale, and The Cheviots – the Authority works to encourage local initiatives connecting people and businesses with their environment.

The Northumberland National Park includes a wealth of biodiversity including some within protected sites. There are a number of Special Areas of Conservation (SACs), which have been given special protection under the European Union's Habitats Directive. They provide increased protection to a variety of wild animals, plants and habitats and are a vital part of global efforts to conserve the world's biodiversity. The National Park Biodiversity Action Plan highlights in particular the importance of Upland Heathland, Blanket Bog, Upland Hay Meadows, Semi-Natural Woodland and Rivers and Burns as well as some special species such as the black grouse and red squirrel.

Northumberland National Park has some of the finest multi-period archaeological landscapes in Europe, and they are largely unstudied and unspoiled. The World Heritage Site of Hadrian's Wall in the south is of prime importance but there are several hundred Scheduled Ancient Monuments and Listed Buildings throughout the Park and the northern uplands can boast upstanding settlement evidence going back to the Bronze Age. The Park's landscape is testimony to the impact of generations of settlers and farmers over several millennia.

The aim of this Geodiversity Audit and Action Plan

The principal aim of this plan is to provide the framework necessary for informing the sustainable management, planning, conservation and interpretation of all aspects of the geodiversity of the Northumberland National Park and surrounding area well into the future. As the first comprehensive plan for a National Park it is intended to serve as an example of good practice for National Parks and other protected areas in Great Britain.

The Government's Policy and Planning Statement 1: *Delivering Sustainable Communities* requires that plan policies and planning decisions should be based on up-to-date information about the environmental characteristics of an area. These characteristics include the relevant biodiversity and geological resources (geodiversity). Recommendations and action points for any aspect of geodiversity can only be meaningful and credible if they are devised in the light of a sound, modern understanding of the areas earth science. Accordingly, the key elements

Objectives of this Geodiversity Audit and Action Plan

- To raise awareness of the fundamental importance of geodiversity in the sustainable management of the district
- To improve knowledge and understanding of the geodiversity resources within the district
- To provide non-specialists with an easy-to-use guide to the geodiversity of the district
- To identify the main geological formations and features, and to evaluate their contribution to geodiversity within the district
- To place these geological formations and features in their regional, national and, where appropriate, international context
- To evaluate those geological sites within the district which currently enjoy statutory or non-statutory protection and to identify any elements of the district's geodiversity not represented in these sites and to make suggestion for how this might be addressed
- To inform and contribute to the process of maintaining or bringing geological SSSIs in the district into favourable condition
- To identify links between the district's geodiversity and its landscape character, biodiversity and economic and cultural history
- To identify threats to geological features
- To identify opportunities to enhance the value of geological features
- To recommend strategies to conserve geological features
- To identify a network of representative sites which encapsulate the essential features of the district's geology
- To identify features and topics which can contribute to sustainable 'geotourism'
- To engage industry, local communities and voluntary groups in the district's geodiversity and encourage them to become involved in understanding and celebrating geodiversity



A guided walk at the Drake Stone, Harbottle © Roger Coulam

- To 'embed' geodiversity into future planning, management and interpretation policies
- To recommend strategies for continued monitoring of the district's geodiversity
- To comment on geodiversity issues relevant to planning, development, mineral extraction and environmental monitoring and management
- To provide a sound expert basis for framing specific recommendations and action points for the district's geodiversity
- To inform elected members sitting on regional or local planning committees about ways their activities will be able to promote geodiversity and geological conservation
- To assist individuals and community groups with an interest in how consideration of geodiversity can improve their environment. The report will help guide expectations about what can be delivered in geological conservation and interpretation and how they might be involved
- To help developers and their agents address geodiversity considerations in planning applications and in the design of development

of the area's geology are outlined here in sufficient detail to inform and underpin specific recommendations and action points. They also enable a user, who may not be a trained geologist, or who may be unfamiliar with the area, to appreciate the relevance and contribution each element makes to its geodiversity.

A number of different approaches have been adopted nationally to assess the contribution of geodiversity to a region. The most recent, the *Geodiversity Profile*, has been developed "...as an independent, standardized, quantitative procedure for describing and valuing the knowledge and contribution of geodiversity at geological sites, particularly quarries". It is important to note that in the geodiversity profile, as in this audit, it is the nature of the geodiversity at a site and its wider significance that are of prime concern, rather than any prior designation or access considerations.

Geodiversity and the planning system

Although the parallel concept of biodiversity has long been established as an essential element in sustainable planning and management strategies, until relatively recently geodiversity was commonly taken for granted

or ignored, despite its fundamental importance in underpinning biodiversity. However, the publication in 2005 of Planning Policy Statement (PPS) 9: *Biodiversity and Geological Conservation*, which sets out the Government's national policies on the protection of biodiversity and geological conservation, introduces the concept of geodiversity into the planning process. It is now stated clearly that both Regional Spatial Strategies and Local Development Frameworks must have regard to the national guidance on geodiversity set out in PPS9. Complementary to PPS9, *Planning for Biodiversity and Geological Conservation – A Guide to Good Practice* (2006) provides guidance, via case studies and examples, on the ways in which regional planning bodies and local planning authorities can help deliver the national policies in PPS9 and comply with legal requirements. The key principles in PPS9 require that planning policies and decisions not only avoid, mitigate or compensate for harm, but seek ways to enhance and restore biodiversity and geology. The guidance suggests ways in which these principles might be achieved. These include identifying the geodiversity value of previously developed sites and the opportunities for incorporating this in developments, as well as recognizing areas of geological value, which would benefit from enhancement and management.

View south-east to Echo Crags from Ramshope Burn



Geodiversity must be considered at every stage of the planning and development process, and at all scales (local, regional and national), following clear policy guidelines on the best ways to conserve it. Perhaps the greatest threat to geodiversity is inappropriate development. New developments often destroy or conceal valuable geological exposures and disrupt the natural processes that helped form them. When any development – large or small – is proposed, planners should assess its potential impacts on geodiversity, take steps to mitigate any damage that cannot be prevented, and identify opportunities that might benefit geodiversity. For example, some developments might allow the creation of more rock exposures, or offer an opportunity to re-establish natural systems; in others, planning permission may insist on mitigation, such as future monitoring and maintenance work. Road improvement works may require the construction of new cuttings and such operations offer opportunities to reveal hitherto unexposed geological sections, either temporarily during construction, or as permanent features. Geodiversity is not and should not be regarded merely as concerned



Rounded hills formed by rocks of the Cheviot Volcanic Formation in upper Coquetdale, looking north-west from Barrowburn towards Mozie Hill
© Graeme Peacock www.graeme-peacock.com

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.

Protecting geodiversity

In the past, many geologically important sites have been conserved on an individual basis, but it is now recognized that in the future it will be important to work together with others to conserve geodiversity in the wider landscape and not just as isolated pockets. Although it is not easy to develop a coherent, integrated approach to the protection of geodiversity, there are now many examples of good practice to follow, and the rewards of co-operation – arriving at better solutions for the environment while meeting social and economic objectives – are clear.

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 district's geodiversity. The Government circular:

Biodiversity and Geological Conservation – statutory obligations and their impact within the planning system provides administrative guidance on the application of the law in England relating to planning and nature conservation.

Geological conservation has traditionally had a lower profile than wildlife conservation, but continues to grow in both profile and practical involvement of official bodies and voluntary organisations. This is due partly to an increased recognition of the importance of geology to society, science and education, and as a recreational and inspirational resource. It is also a reflection of the increasing threat of damage and destruction faced by the natural environment, including geological sites.

The varied natural, economic and cultural landscape of the district includes a wealth of earth science features and sites which not only define and contribute to its distinctive character, but which have interest and importance which extend beyond its confines. Such features may be recognised in a number of ways. They may enjoy some form of legal protection through scheduling as Sites of Special Scientific Interest (SSSIs), or through some form of non-statutory designation, for example, as Sites of Nature

Conservation Importance (SNCl) or as Regionally Important Geological or Geomorphological Sites (RIGS).

It is a common misconception that geological and landscape features, other than those already afforded some measure of protection, 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, 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.

Geological conservation in England

Statutory designations

Sites of Special Scientific Interest (SSSIs)

A representative sample of the best of the Country's wildlife and geological sites enjoy legal protection through their designation as SSSIs. The designation was introduced as one of the provisions of the 1949 National Parks and Access to the Countryside Act and has been maintained through subsequent legislation. The term SSSI is used today to denote an area of land notified as being of special nature conservation interest under the Wildlife and Countryside Act 1981. The Countryside and Rights of Way (CROW) Act 2000 greatly strengthened the legislation relating to the conservation of geology and wildlife in England and Wales by placing emphasis on management rather than just conservation of SSSIs. It requires that all public bodies should conserve and enhance SSSIs. The CROW Act also makes it an offence for anyone to knowingly or recklessly damage an SSSI, including by irresponsible mineral or fossil collecting. The network of SSSIs in England is the responsibility of Natural England. Designation as an SSSI does not imply any right of access for third parties. Neither does it follow that the site is necessarily appropriate for public interpretation.

In 2000 the government published a series of Public Service Agreements, which included for the Department for Environment Food and Rural Affairs (Defra), an objective to enhance opportunity in rural areas, improve

enjoyment of the countryside and conserve and manage wildlife resources. This included the target of bringing into favourable condition, by 2010, 95% by area of all SSSIs.

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. Sites were selected in consultation with experts, including BGS geologists, in the various topics covered. Large numbers of sites were considered but, in general, only one site was selected as the best example of each aspect of geology under consideration. GCR sites were selected on the basis of their scientific value rather than their educational or historical importance. Three criteria were applied in selecting the GCR sites:

- sites of international geological importance
- sites that are scientifically important because they contain exceptional features
- sites that are nationally important because they are representative of a geological feature, event or process which is fundamental to understanding Great Britain's geological history

Once selected, a GCR site was then proposed as a potential SSSI. In England, it is only when a site is approved as an SSSI by Natural England's Council that it receives full legislative protection. Publication of descriptions of GCR sites is being undertaken by the Joint Nature Conservation Committee in a series of 45 thematic volumes due to be completed in 2007.

National Nature Reserves (NNRs)

A number of the best SSSIs are declared as National Nature Reserves, many of which are important in an international context. These are managed to conserve their habitats and geology and to provide special opportunities for appreciation of nature and scientific study. Almost all NNRs have some form of access provision.

Heritage designations

Scheduled Ancient Monuments (SAMs)

As well as the ancient monuments associated with

historical periods of occupation, some more modern sites of former extractive industries within the district have the statutory designation of Scheduled Ancient Monument. SAM status imposes certain legal restrictions on activities which may be permitted at a site. Focussing upon archaeological considerations, the scheduling does not take into account the often intimately associated nature conservation interests, including geodiversity. A number of SAMs encompass features of some geodiversity interest or importance.

The Hadrian's Wall World Heritage Site

Stretching from the coast of West Cumbria to the North Sea, Hadrian's Wall survives today as a ruined but authentic structure. Hadrian's Wall was inscribed as a World Heritage Site (WHS) in 1987. It met the criteria for outstanding universal value set by UNESCO's World Heritage Convention as the most complex and best preserved of the frontiers of the Roman Empire. The initial definition of the WHS included only the Scheduled Ancient Monument. The boundaries are currently under review and it is likely to be proposed that the whole area between the Wall and the Vallum should be included within the WHS. A buffer zone, known as the 'Setting',

is mapped as the inner and medium visual envelope of the WHS, extending up to 6 kilometres north and south of the site. A Management Plan for the site was published in July 1996, the first to be written for any of the 24 UK World Heritage Sites. A revised plan was published in 2002. A new management plan is currently in preparation. One purpose of the Plan is to balance and accommodate the differing, and potentially conflicting, interests of those who manage and conserve the site with those who wish, or need, to use and enjoy it. The classic, central section of the Wall is within the district under consideration and this Geodiversity Audit and Action Plan will serve to aid and complement the implementation of the Management Plan for the Hadrian's Wall WHS. The Hadrian's Wall World Heritage Site includes SSSIs designated for their geology.

Non-statutory designations

Wildlife sites

Local authorities for any given area may designate certain areas as being of local conservation (including geological) interest. The criteria for inclusion, and the level of protection provided, if any, may vary between areas. Most individual counties have similar schemes.

Hadrian's Wall following the line of the Great Whin Sill west towards Cawfields © Graeme Peacock www.graeme-peacock.com



These sites, which may be given various titles such as *Listed Wildlife Sites (LWS)*, *Local Nature Conservation Sites (LNCS)*, *Sites of Importance for Nature Conservation (SINCS)*, or *Sites of Nature Conservation Importance (SNICIs)*, together with statutory designations, are defined in Local Development Frameworks under the Town and Country Planning system and are a material consideration when planning applications are being determined.

Regionally Important Geological and Geomorphological Sites (RIGS)

RIGS are locally or regionally important sites, usually identified within a county or region, that are considered worthy of protection for their geological or geomorphological importance. RIGS are selected and managed by RIGS groups, sometimes called trusts. Designation of sites as RIGS is the responsibility of RIGS committees which bring together professional geologists, planners, representatives of local organisations and enthusiastic amateurs. Although RIGS have no statutory protection, the details of many RIGS have been passed

to local planning authorities and these sites receive some protection through planning policies. Potential RIGS are identified using four nationally agreed criteria:

- The value of a site for educational purposes in life-long learning
- The value of a site for study both by professional and amateur earth scientists
- The historical value of a site in terms of important advances in earth science knowledge, events or human exploitation
- The aesthetic value of the site in the landscape, particularly in relation to promoting public awareness and appreciation of earth heritage

RIGS are broadly analogous 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.

Earth Science Conservation Classification

The Earth Science Conservation Classification (ESCC) was originally devised as a conceptual classification for geological sites by the Nature Conservancy Council (NCC) in 1990. Since then, the ESCC has been used extensively by all of the UK statutory conservation agencies as a primary tool in the conservation and management of geological sites. The ESCC uses site type as the basic unit of classification. The classification allows generic threats and conservation strategies to be defined for the different site types and forms the basis for monitoring and condition reporting on geological sites, paralleling the Biodiversity Action Plan Broad Habitat Type for biological conservation. The ESCC has 16 different site types in three main categories: exposure or extensive (E), integrity (I) and finite (F). The distinctions between the three main categories are important, reflecting fundamental differences in conservation strategies.

Exposure or extensive (E) sites contain geological features which are relatively extensive beneath the surface. The basic principle is that removal of material does not cause depletion or damage to the resource,

as new material of the same type is being exposed as material is removed. The main management aim is to achieve and maintain an acceptable level of exposure of the interesting features.

Integrity (I) sites are geomorphological and are characterised by the need for holistic management. Damage to one part of a site may adversely affect the site as a whole. In the case of active process sites, the fundamental principle is to maintain the active processes by non-interference as far as possible.

Finite (F) sites contain geological features that are limited in extent so that removal of material may cause depletion of the resource. The features are often irreplaceable if destroyed. The basic management principle is to permit responsible scientific usage of the resource while conserving it in the long term. Hence, it is often necessary to implement controls over removal of material.

Further information, including the complete classification and criteria and methods for the monitoring of sites can be found in *Geological conservation: a guide to good practice*.

Geological conservation in the district

Geological SSSIs

The district includes 16 SSSIs notified primarily for their geological importance, all of which are GCR sites. In addition, many of the SSSIs notified for other reasons include features of geological significance.

RIGS

There are currently no RIGS sites designated within the district. A Northumbria RIGS Group has formed recently and a number of opportunities for involvement of the group within the district have been identified in the Action Plan. Some sites identified during the audit may be candidates for RIGS.

Sites of Nature Conservation Importance (SNCl)s

Within Northumberland, an SNCl is defined as a discrete area of land that is considered to be of significance for its wildlife and/or geological/geomorphological features in at

least a county context. Northumberland Wildlife Trust (NWT) designates geological SNCl)s primarily so that the local authorities (County and District councils) and other organisations, including landowners, may be aware of their location and of the need to consider the conservation of such sites when developments are proposed. Such sites are recorded as part of Local Development Frameworks. The management of SNCl)s is not currently co-ordinated as a whole, but individual sites may be under specific management for conservation.

The geological SNCl)s serve a similar function to RIGS within the planning process. However, they have been selected according to different criteria, most notably with less emphasis on access than is usual for RIGS, and generally do not benefit from the practical care that an enthusiastic RIGS group might bring.

Climbing on the Fell Sandstone at Simonside © NNPA



The process of designating geological sites in Northumberland started in the early 1960s when a list of 26 quarries was proposed for submission to the County Planning Officer for inclusion in an 'interesting sites' record. In the 1970s, geological information, now held at the Hancock Museum, was gathered as part of the 'Draft National Scheme for Geological Site Documentation'. The sites so identified were accorded no protection. However, following further examination of sites by two geologists in the late 1970s, NWT had recorded over 60 geological sites throughout Northumberland as SNCIs by 1983. Formal designation by NWT is based on confirmation by a panel of experts.

Do protected sites adequately represent the geodiversity of the district?

Sites which currently afford statutory or non-statutory protection to geological features have generally been selected to reflect the regional or national importance of the features exposed. It is important to appreciate that whereas most of these sites are identified or described in the geological literature, their listing implies no rights of access. Most lie on private land and access to them is entirely at the discretion of the relevant landowner. Apart from some of the SNCIs, sites have not in general been chosen for the purpose of representing the main elements of the district's geodiversity. One purpose of this geodiversity audit is to examine whether this representation is adequate and, if appropriate, to identify additional sites to achieve more complete and comprehensive coverage.

Features of earth science importance within sites currently designated for protection of their biodiversity or archaeological interest

In addition to those designated primarily for their earth science importance, the district includes a substantial number of SSSIs, SNCIs and NWT Reserves designated primarily 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. Access arrangements exist for NWT reserves, generally free to the public, although occasionally requiring a written permit to be obtained.

Potential conflict of interest

Sites or features selected for any form of protection can rarely, if ever, be satisfactorily regarded as 'single interest' sites. Statutory designation of sites, as SSSIs or SAMs, offers a 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 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 interests 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 or quarry 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. Similarly, an abandoned quarry which displays extremely important geological sections may also support interesting or important plant communities, may be a bat roost, or may be associated with historically interesting buildings such as limekilns. Thus, there is a need to resolve the potential for conflict of conservation interests and it is hoped that this audit will help to identify such conflicts and opportunities to combine interests.

Enhancement of interest

A multi-disciplinary approach to conservation of all 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, often the underlying principle seems to have been overlooked, or even ignored, in many previous conservation initiatives.

Opposite: Hadrian's Wall above a cliff in the Great Whin Sill, with Crag Lough behind. Milecastle 39 in the foreground
© Graeme Peacock www.graeme-peacock.com

Section 2

Roots of our geological heritage

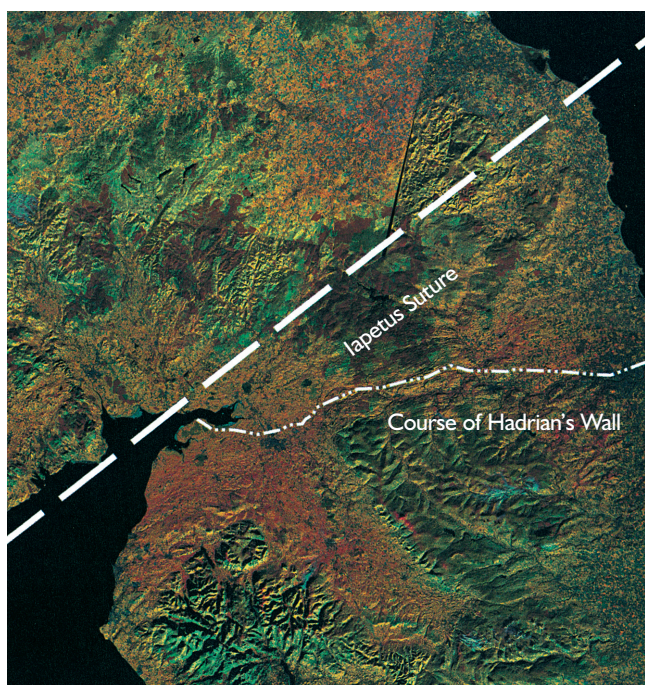


Evolution of the rocks and landscape of the district

Although the Earth is almost 4600 million years old, events from only about the last 440 million years are recorded in the rock record of the district. The following account sets the scene for the discussion of the region's geodiversity with a summary of the geological evolution and development of the landscape.

England's northern border coincides approximately with the Iapetus Suture, one of the fundamental geological boundaries in Britain. The suture is the trace of the junction between two ancient continents that were once separated by a vast ocean, known as the Iapetus Ocean, up to 1000 kilometres wide at its maximum extent in late Cambrian times, about 500 million years ago. The Iapetus Suture has since been buried by more recent sediments but its shallow inclination northwards beneath northern England can be imaged from geophysical data. Renewed movements affecting the Suture have controlled the geological history of the area.

The approximate position of the buried Iapetus Suture, shown on a satellite image taken by the LANDSAT 5 Thematic sensor



Globe showing position of the Iapetus Ocean, approximately 500 million years ago and the areas that were to become present-day Great Britain and Ireland. A – Scotland and the north of Ireland B- England, Wales and the south of Ireland

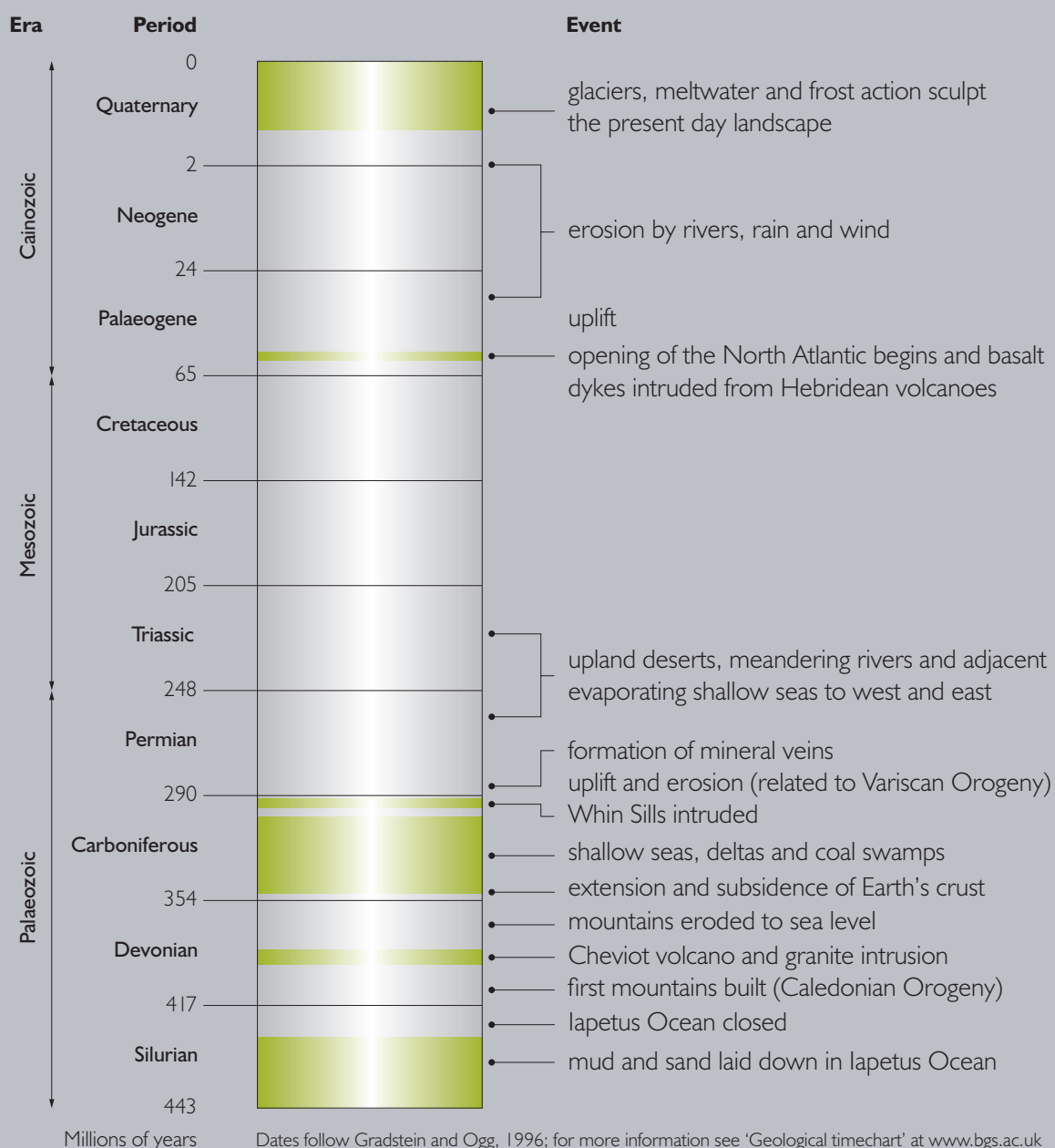
In early Palaeozoic times the continent of Laurentia lay to the north of the Iapetus Ocean. Forming part of the continent's south-eastern margin were Scotland and the northernmost part of England, together with the north and west of Ireland. At a latitude of about 60° south lay the rest of England and Wales, on the smaller continent of Avalonia, together with the south and east of Ireland, parts of mainland Europe and fragments of the maritime states of North America.

From late Cambrian times, plate tectonic processes gradually closed the Iapetus Ocean resulting in the convergence and ultimate collision of the two continents, Laurentia and Avalonia, and building the Caledonian mountain belt as a consequence. The eroded core of this belt can be traced today through Scandinavia, Scotland, Ireland, and on into Greenland and maritime North America. Continental collision began around 425 million years ago in mid-Silurian times and the leading edge of Avalonia was driven at a shallow angle northwards beneath Laurentia. The oldest rocks exposed at the surface today in the district comprise the Riccarton Group and date from this period. These rocks were deposited as marine muds and sands in the much diminished remains of the Iapetus Ocean.

A timescale and summary geological history

Geological time is divided into the Eras and Periods shown, with the ages before the present day given in millions of years. The colour bands in the chart indicate those periods of geological time represented in the district's rocks. Also included are events that occurred during the long periods of time for which no record remains; their presence has been inferred from evidence in adjoining areas.

The enormity of geological time may be appreciated by representing the whole of Earth history by a single day. On this scale, the oldest rocks in the National Park formed around 9.45 pm, the Carboniferous limestone and sandstone that make up most of the central and southern parts were laid down between 10.10 and 10.30 pm, and the Quaternary ice ages began less than one minute to midnight. Man first walked across the Northumberland moors at less than one second to midnight.



By early to mid-Devonian times the sediments that had accumulated on the shrinking Iapetus Ocean floor were compressed intensely between the colliding continents. This folded, cleaved and uplifted the rocks during an event termed the Caledonian Orogeny.

Towards the end of, or closely following, the Caledonian Orogeny, volcanoes formed in the area of the Cheviot Hills. These are thought to have been low-lying, shield-like structures formed by the amalgamation of many flows of magnesian- and iron-rich lava erupted from numerous vents, rather than the classic conical volcanoes typical of modern day western North and South America. A large mass of silica-rich magma was injected and solidified beneath the volcanoes to form the Cheviot Granite Pluton, locally baking and re-crystallising (metamorphosing) the surrounding volcanic rocks. Subsequently, the extinct volcanoes were eroded intensely by rivers. Relics of the alluvial fans of gravel deposited at the edge of the ancient upland by these rivers are preserved today as the lower Carboniferous Roddam Dene Conglomerate.

At around 410 million years ago, in the early Devonian Period, a similar body of granite to the Cheviot Pluton was intruded beneath what is today the North Pennines. Although this granite – the Weardale Granite (or North Pennines Batholith) – does not extend under the district, its presence was to have a significant affect on the district's subsequent geological evolution.

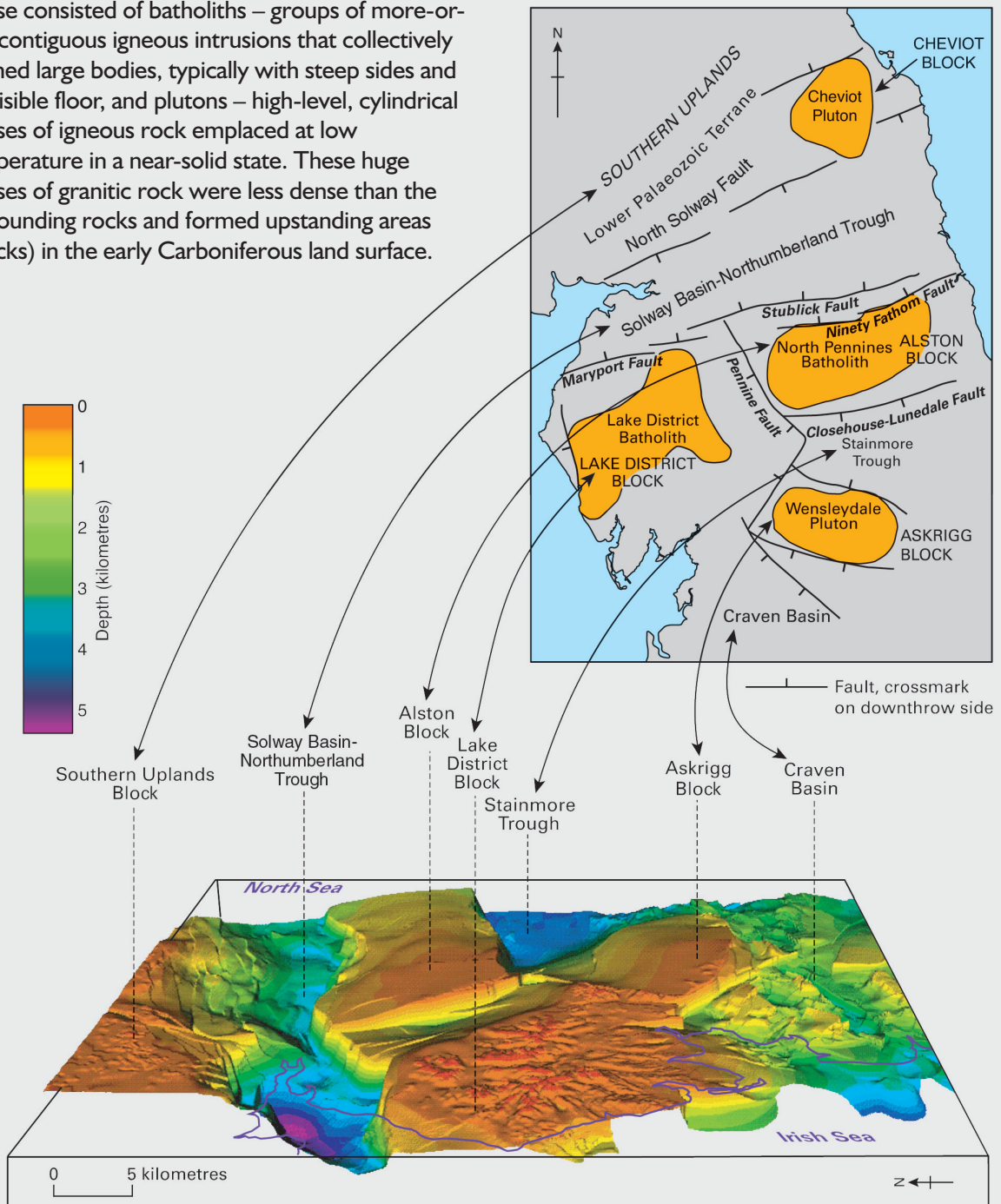
In early Carboniferous times global continental movements resulted in a general north-south extension of the Earth's crust beneath the area now occupied by northern Britain and neighbouring parts of the North Sea. Movement along a number of fractures, or faults, defined a pattern of 'basins' and 'blocks'; and caused the sea to flood much of the area that had been land at the end of the Devonian. In northern England, the crust overlying the Iapetus Suture subsided and broke along east-west fractures forming, amongst others, the Stublick–Ninety Fathom Faults. The presence of the Weardale Granite to the south of these faults kept this area 'buoyant' as granitic rocks are significantly less dense than most other rock types. Consequently, subsidence to the north of the Stublick–Ninety Fathom Faults, in the area that is now central Northumberland, was more rapid than that to the south, in the area that is now the Northern Pennines. A large 'hole', known today as the

Northumberland Trough, developed in central Northumberland, and as a result a much greater thickness of Carboniferous rocks accumulated here than in the North Pennines. Initially, crustal stretching and subsidence within the Northumberland Trough were rapid enough to allow basaltic magma, generated in the underlying Earth's mantle, to reach the surface along fractures, and to erupt as lava. The remains of these eruptions are preserved in the district along the southwest margin of the Cheviot massif as the Cottonshope Volcanic Formation.

At the beginning of Carboniferous times, the area that was eventually to become northern England lay within equatorial latitudes. During the Carboniferous Period it drifted northwards across the Equator from 5° to 10° south to about 5° north. This movement took the region from the southern hemisphere tropical arid zone, through the much wetter equatorial zone during much of the Carboniferous, into the northern hemisphere tropical arid zone in latest Carboniferous times. Over millions of years of the Carboniferous Period, the whole region subsided beneath a wide, shallow, tropical sea in which an abundance of lime-secreting organisms gave rise to accumulations of limestone. Large and vast rivers, draining from upland areas to the north and north-east, in the region occupied today by the Southern Uplands, brought periodic influxes of sand, silt and mud and built wide deltas into the Carboniferous sea. Lush forests flourished on top of the deltas and peat accumulated on the swampy forest floors. As the deltaic sand, silt and mud became buried by successive layers of sediment, they compacted to form sandstones, siltstones and mudstones; the peat became preserved as thin coal seams. The cycle of marine limestone followed by deposition, in regular sequence, of muds, silts and sands, was repeated many times during the Carboniferous Period, giving rise to a highly distinctive repetition of limestone, mudstone, siltstone and sandstone. These sediments are preserved today in the rocks of the Yoredale Group. With the passage of time, influxes of deltaic sediment became more frequent and widespread, and the lush forests became more extensive. By the late Carboniferous Period the whole area had become a low-lying, deltaic swamp crossed by wide, meandering rivers. The numerous, extensive and thick coal seams of the Pennine Coal Measures record the periodic development and burial of vast volumes of swamp vegetation over very wide areas.

'Blocks' and 'basins' developed at the beginning of the Carboniferous Period in the region that was to become northern England

Granitic rocks had been intruded from below into the existing rocks prior to Carboniferous time. These consisted of batholiths – groups of more-or-less contiguous igneous intrusions that collectively formed large bodies, typically with steep sides and no visible floor, and plutons – high-level, cylindrical masses of igneous rock emplaced at low temperature in a near-solid state. These huge masses of granitic rock were less dense than the surrounding rocks and formed upstanding areas (blocks) in the early Carboniferous land surface.



About 295 million years ago, towards the end of Carboniferous times, Earth movements, related to a period of mountain building known as the Variscan Orogeny in what is now southern Europe, uplifted, tilted and locally folded the Carboniferous rocks and created an upland area across what was to become northern England. This event also stretched parts of the crust beneath northern England to allow huge volumes of magma to rise, spread out and solidify between the layers of sediment, forming the Whin Sills. The crystallised magma formed sheets of the hard black rock known as dolerite. The injection of magma at temperatures of at least 1100°C metamorphosed adjacent sediments; sandstone became much harder, mudstone was turned into hornfels (known locally as 'whetstone'), and limestone was turned into marble.

Soon after the intrusion of the Whin Sills, mineral-rich waters, warmed by the Weardale Granite beneath the North Pennines, began to circulate through cracks and

faults in the rocks deep beneath the southern part of the district. As these solutions cooled, their dissolved minerals crystallised to form the veins found in the Haydon Bridge area; these veins form an outlying part of the Northern Pennine Orefield.

Evidence for most of the geological events affecting the region from this time until the ice ages of the Quaternary Period can be inferred only from outside the region as all traces of the succeeding succession of rocks have been removed by erosion. However, evidence for the development of the North Atlantic Ocean during Palaeogene times is present within the district. Significant stretching of the Earth's crust during the initial stages in the opening of the North Atlantic Ocean, approximately 60 to 55 million years ago, resulted in extensive volcanic activity centred in the Hebrides and Northern Ireland. Basaltic magma dykes, a distant expression of this volcanic activity, were intruded over much of the district. The Acklington Dyke is one such example. The opening

The striking pattern of ridges formed by tilted Carboniferous rocks, which epitomises Hadrian's Wall country, is most spectacularly seen from the air. In this view ridges of resistant sandstone and limestone are clearly seen, though most prominent is the scarp of the Great Whin Sill, which casts dark shadows on its northern side near Sewingshields (1). The Whin Sill crags can be followed westwards towards Housesteads (2) and Crag Lough (3), though their continuity is locally disrupted by several faults © AirFotos Ltd.



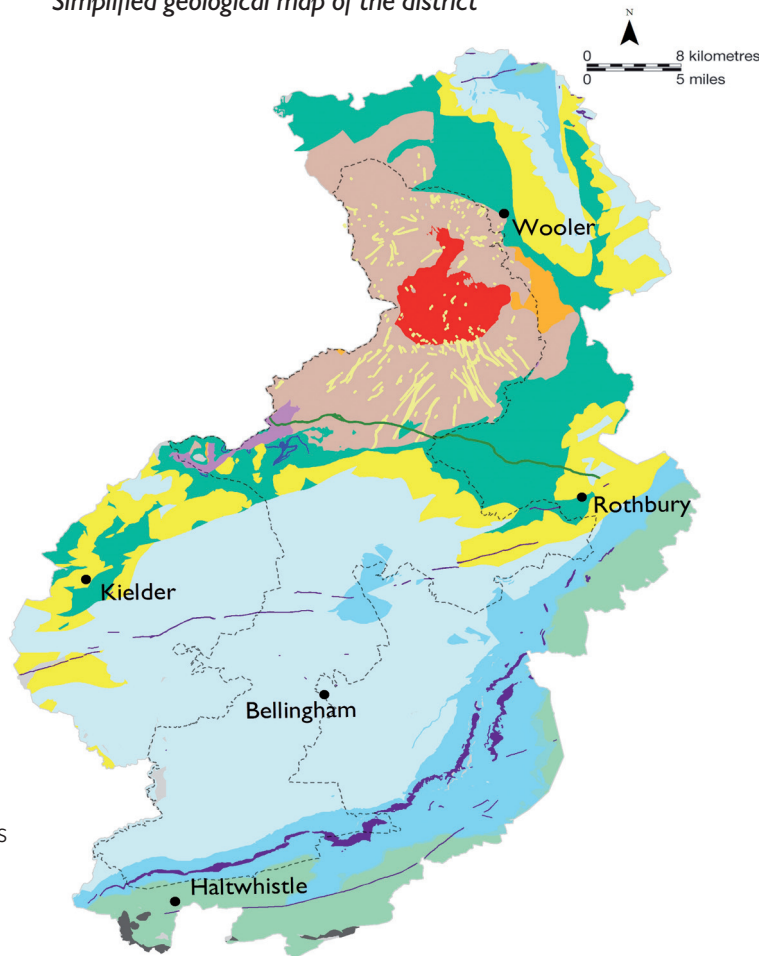
of the ocean elevated much of northern Britain to begin a long period of erosion and landscape development during Cainozoic times.















The start of the Quaternary Period, about two million years ago, saw the beginning of a period of global cooling. Throughout Quaternary time the climate fluctuated rapidly over very short timescales, from warmer temperatures than those of today, to full glacial conditions. ice-sheets began to grow across the uplands of Britain and Ireland. As the ice-sheets thickened they flowed out of the uplands and extended southwards across much of Britain and the adjacent continental shelf.

The effects of these glaciations can be seen in the landscape and deposits of the whole of the district. Lowland areas are blanketed with thick sequences of till (boulder clay), testament to the massive erosive and transportational processes of the ice. Large boulders transported by the ice can be found all over the district. These are known as 'erratics' as their individual rock types do not match those of the underlying bedrock and show that they have travelled some distance, mostly from southern Scotland and northwestern England. Large areas supported very fast-flowing portions of the ice-sheet, called ice streams, and their effects can be seen in the streamlining of bedrock surfaces and the moulding of surface sediments. During warmer intervals, the ice retreated back into the neighbouring uplands. During the retreat, huge volumes of meltwater transported large amounts of sand and gravel both beneath and around the wasting glaciers. Great swathes of countryside were buried by this glaciofluvial material deposited in outwash deltas, such as that at Woodbridge, in vast lakes like the one that occupied the Milfield Plain during this time, or as chaotic deposits of mounds, hollows and abandoned river valleys such as those found near Roddam and Wooperton.

After the retreat of the last ice-sheets, around 15 000 years ago, the climate remained cold for some time, allowing deposits of peat to develop locally. After a final, 1000 year-long intensely cold period, the climate improved dramatically and the first pioneer forests, composed of birch, aspen and pine, colonised the district followed by a floral succession culminating in mixed deciduous woodland. Throughout this time alluvial silts and muds continued to accumulate, as they do today, along major rivers and streams.

Simplified geological map of the district



- | | | |
|--------------------------------------|---|--------------------------------------|
| Cainozoic 'Tertiary' |  | Acklington Dyke |
| Early Permian - Carboniferous |  | Whin Sill-swarm and associated dykes |
| Carboniferous |  | Pennine Lower Coal Measures |
| |  | Stainmore Formation |
| |  | Alston Formation |
| |  | Tyne Limestone Formation |
| |  | Fell Sandstone Formation |
| |  | Ballagan Formation |
| Devonian |  | Cottonshope Volcanic Formation |
| |  | Kinneswood Formation |
| |  | Cheviot Dyke-swarm |
| Silurian |  | Cheviot Granite Pluton |
| |  | Cheviot Volcanic Formation |
| Silurian |  | Riccarton Formation |

The influence of geodiversity in the landscape

Geodiversity is intrinsically linked to many facets of the district's landscape, from its most obvious manifestation in the Whin Sill ridge to the more subtle relationship of plants to the soil and the human use of natural resources. Indeed, the landscape we see today has been modified to such an extent that it can be difficult to identify the fundamental contribution of geological processes to the physical landscape. Consequently, as a first step in the analysis of landscape character, it is necessary to produce an assessment of the physical landscape that is not strictly dictated by formally designated geological boundaries. The objective of this exercise is to obtain a 'feel' for the landscape, and for this it seems logical to devise a set of criteria by which the landscape could be interpreted in terms of its visual physical characteristics. As the broad physical landscape character of the district as a whole can be appreciated best by looking at it from the air, a computer-generated, photorealistic hillshade model was created from digital elevation data. This model shows landscape and landform features at a very high resolution. It can be used to delimit areas of similar featuring, and therefore geological style, on the basis of their broad visual character.

It is clear from the study that geological or geomorphological processes, rather than rock type or deposit, are the critical factors in determining the broad landscape character of the district: most notably the different processes involved in glaciation and deglaciation of the landscape. Even in those areas of the district where bedrock is at the surface, the broad physical landscape has resulted from the interaction between the rock and these geomorphological processes.

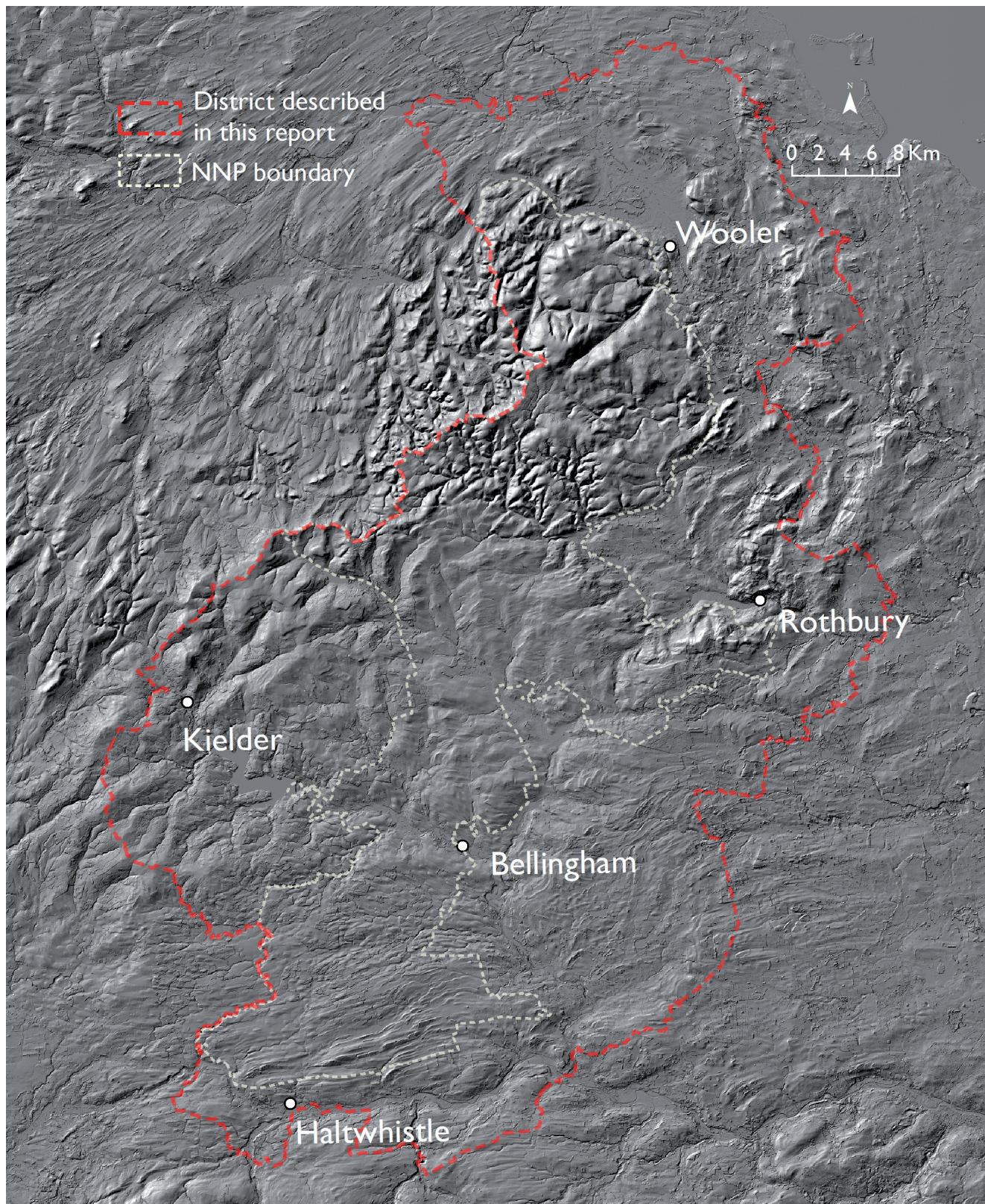
Two of the most impressive landscapes of the region, namely the Cheviot Hills in the north and the escarpment on which Hadrian's Wall stands in the south, are composed largely of igneous rocks.

The rocks are at, or very close to, the surface throughout the Cheviots, but the physical landscape shows dramatic variation as a result of the response of the rocks to different glacial processes. In the eastern Cheviot, the upland slopes are smooth and convex, often covered only by thin deposits of weathered material. Tors of granite and metamorphosed volcanic rocks characterise the hilltops. By contrast, the igneous rocks of the western Cheviot are covered in a thick layer of degraded and weathered rock in a landscape characterised by concave slopes and 'V-shaped' valley profiles, with large accumulations of weathered rock at their bases.

View south-east from Hedgehope Hill showing Long Crags, Housey Crags and Langlee Crags, tors of metamorphosed volcanic rock
© Graeme Peacock www.graeme-peacock.com



A photorealistic hillshade model of the region, derived from the NEXTMap® digital elevation model (© Intermap Technologies Inc.) based on low-level radar survey of the ground surface



The striking north-facing escarpment of the highly resistant Whin Sill, with its bare rocky cliffs and long, gentle southerly slopes, provided the Roman civil engineers with a natural defensive site for the construction of Hadrian's Wall. Adjacent to the Whin Sill in the Wall country, where the Carboniferous sedimentary rocks have been tilted towards the south, differential erosion of the component rocks has produced a pronounced east-west orientated scarp and dip topography, which has been accentuated by the scouring action of eastward flowing ice during the last glacial period (p. 22).

The comparatively resistant limestones and sandstones typically form scarps or cuestas, often with small rocky scars along their crests, with the outcrops of the weaker mudstones and siltstones marked by lower lying, unexposed 'slack' ground or hollows between the scarps. This landscape, perhaps most strikingly seen when approaching Housesteads from the east in low-angled sunlight, or with a dusting of snow, is one of the most distinctive landscapes in northern England. Few areas of Britain demonstrate so clearly the essential relationship between landform and the underlying geology.

In a similar fashion, much of the central area around Otterburn is characterised by distinctive scarp and dip slopes formed by the differential weathering of Carboniferous sediments. Although, here the cuesta landscape has been partially blanketed by till and only particularly resistant sandstones form small craggy outcrops.

In north Northumberland the grits and sandstones of the Fell Sandstone form the long tiers of crags and bold escarpments that are so conspicuous, giving rise to the

distinctive skyline at Simonside and the crags at Harbottle. Except for the breaks of the Aln and the Coquet rivers, the escarpment completely divides the Cheviot Hills from the sea and deflects all the drainage.

Much of the district is blanketed by glacial till. In lowland areas it commonly masks the bedrock topography. In other places the surface of the till has been smoothed or streamlined into long, linear features by fast-moving overriding ice. To the north of the Wall country, around Henshaw, Haughton and Thirlwall commons, the till has been shaped into elongate, commonly egg-shaped mounds (or drumlins).

Following deglaciation the moulded landscape provided suitable conditions for a wide variety of habitats to develop, such as the Roman Wall Loughs, Border Mires and areas of blanket bog that are important in the landscape today. However, in common with almost every part of Great Britain, the landscape today owes much to human intervention. Agriculture and a variety of industries, including mining and quarrying have all played a part in shaping it. A number of the district's past and present industries are a direct result of locally available mineral raw materials. The nature and properties of local stones have to a large extent determined the character of local buildings. Local materials have combined with the distinctive landscape they helped to shape to create a strong 'sense of place' – unique vistas that have provided an inspiration to writers, poets, musicians and artists throughout the centuries.

The particular influence of each element of geodiversity in the landscape is highlighted in the sections that follow.

Squared blocks of sandstone in Hadrian's Wall near Housesteads © Emma Amsden



Silurian rocks

The Silurian Period extended from 443 to 417 million years ago. Named after a British tribe, the Silures, who lived in southern Wales and the Welsh Borderland, where rocks of this age dominate the exposure, the Silurian is divided into four series: Llandovery, Wenlock, Ludlow and Prídolí. Only rocks from the Wenlock Series, dating from 428 to 422 million years ago, are exposed in the district. Now used internationally, the Wenlock Series was first described from the wooded scarp of Wenlock Edge in Shropshire.

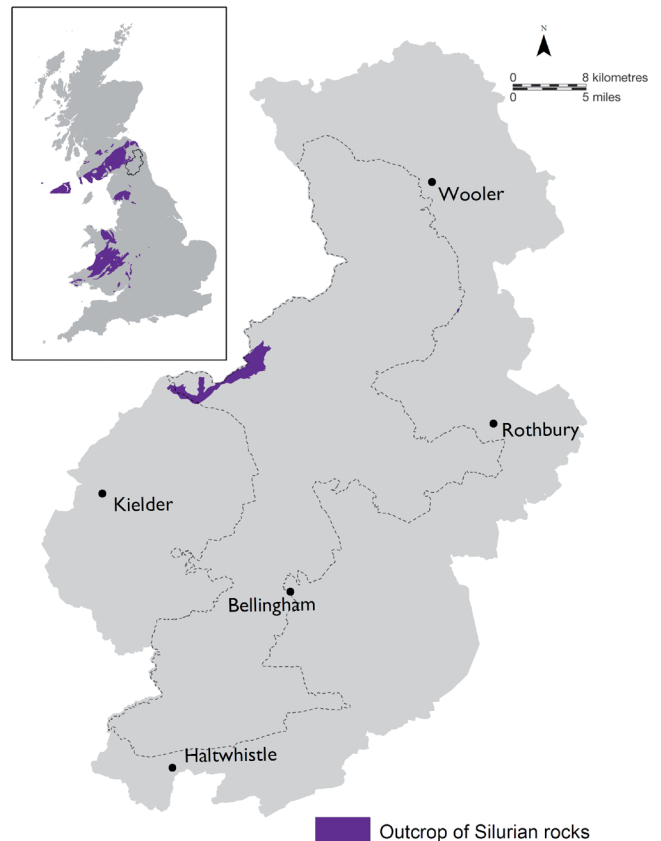
Silurian rocks in Great Britain

The Silurian rocks found in Great Britain were deposited mostly within the deep Iapetus Ocean (p. 18). Thick layers of mud accumulated on the ocean floor, together with substantial amounts of muddy sands, deposited from vigorous turbidity currents carrying sediment from the adjoining continental shelves. As Avalonia began to impinge on the Laurentian continent during early Silurian (Llandovery) time, continental crust started to choke the northward-dipping subduction zone beneath Laurentia, which had formerly subducted only Iapetus oceanic crust. By late Silurian (Ludlow) time, the last remnant of the Iapetus Ocean had been destroyed and the Laurentian margin was being overthrust onto the British segment of Avalonia. As the continents eventually collided, the muds were compressed to form hard mudstones and slates; the muddy sands were compacted to form the sandstones we know today as greywackes.

The fauna of Silurian times evolved rapidly. As a result, the Silurian can be divided into a series of zones according to the changes in the organisms preserved as fossils. Brachiopods, are relatively common in the rocks, but graptolites and conodonts have yielded the most refined Silurian zonations.

The Silurian is extremely well represented in the British Isles, and as the 'type' area for the geological period is important throughout the world.

The distribution of Silurian rocks in the district



Silurian rocks in the district

The basement rocks to the Cheviot Hills igneous complex consists of a steeply dipping sequence of green shales and greywackes that has been assigned to the Silurian Period. The largest outcrop of these rocks is the Coquet Head Inlier, which straddles the Scottish border. The Silurian sequence is unconformably overlain by the basal Old Red Sandstone (Devonian) in the east, and by Carboniferous sediments in the south and west, though much of this boundary is faulted.

The first evidence of a Silurian age for these rocks was the discovery in 1867 of graptolites indicative of a Wenlock age in rocks near Ramshope [NT 73 04]. The Silurian age was confirmed when graptolites were discovered shortly after from a locality in the Coquet valley, although these were believed to be of a younger Ludlow age. However, nearly a hundred years later the

evidence was reassessed and these beds were also considered to be Wenlock in age. In 1982 the beds were assigned to the top of the *Monograptus riccartonensis* zone of the Wenlock Series. The greywackes are similar to those found in the Silurian inliers southeast of Hawick. Sedimentary structures, including flute, prod, and groove casts are common and examples can be found at many outcrops in the Coquet valley, and in the upper reaches of the Kale Water tributaries. The thickness of this sequence, now assigned to the Riccarton Group, is approximately 600 metres.

Steeply dipping shales of the Riccarton Group in Lumsdon Burn



At the eastern edge of the National Park, two small inliers of steeply inclined sediments, consisting of alternations of greywacke and greyish-green laminated shales, occur amongst lavas on the eastern slopes of Fawdon Dene. These sediments appear in every way comparable to those in the Coquet Head Inlier, and are considered to be of the same age. They represent the easternmost exposure of the Silurian platform in the district.

Influence on the landscape

Because of their limited outcrop these rocks have little impact on the landscape. Much of the outcrop is concealed beneath thick deposits of glacial till and peat.

Influence on biodiversity

Because of their limited outcrop these rocks have little impact on the biodiversity.

Economic use

These rocks are not known to have had any economic use within the district and future commercial interest is extremely unlikely.

Conservation issues

None of the outcrops has SSSI protection. Most of the exposures within the district are not thought to be under any significant threat, other than those normally associated with the weathering of natural outcrops and stream sections.

Wider importance/significance

Although covering a relatively small surface area, the few outcrops of Silurian rocks visible within the district are the only evidence of basement rocks within this part of northern England. They therefore contribute significantly to our understanding of the geological history of the area and the geological history of Great Britain.

The sediments of the Coquet Head Inlier contain the diagnostic characteristics which are taken to indicate deposition by turbidity currents. Although few in number, the palaeocurrent (direction of ancient water flow) data are important in consideration of British Wenlock palaeogeography.

Geological SNCI

Whitelee Bridge Road Cutting

Carboniferous rocks

Carboniferous rocks formed approximately 354 to 290 million years ago. The term 'Carboniferous', which is derived from the abundance of carbon-bearing coal seams within rocks of this age, was first applied to rocks in Britain and is now used internationally.

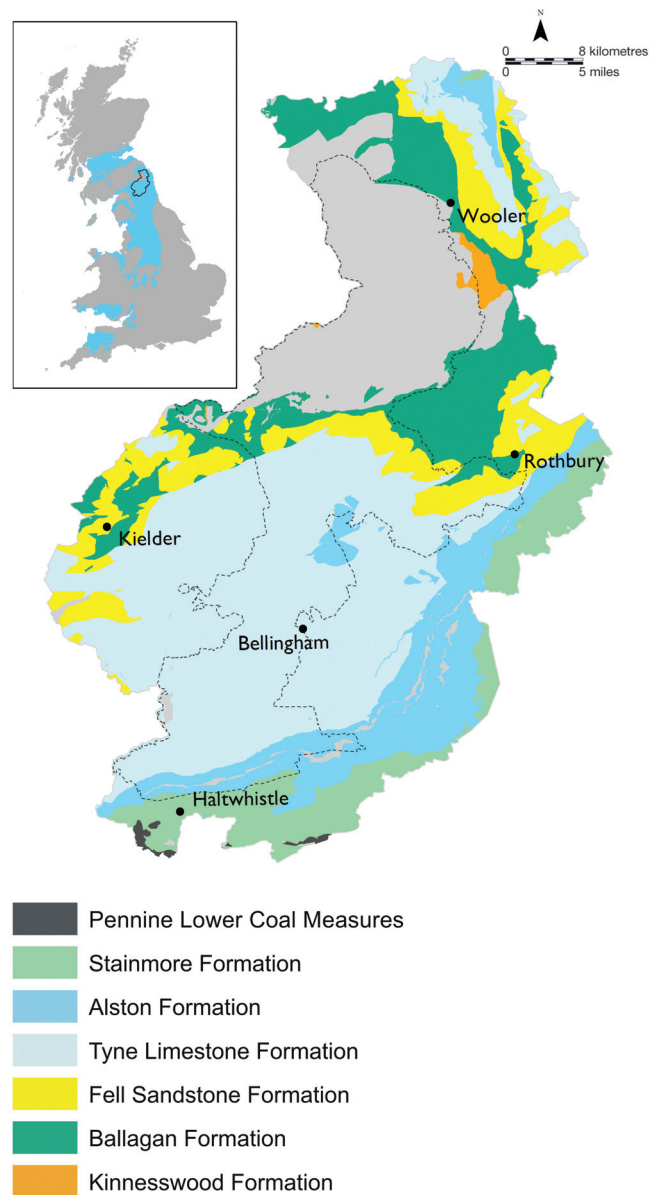
Carboniferous rocks in Great Britain

Sedimentary rocks, sandstones and mudstones (also known as shales) with numerous limestones and seams of coal, make up the greater part of the Carboniferous succession, though igneous rocks are also present. By area, Carboniferous rocks form one of the most extensive geological units in Britain. Carboniferous rocks have attracted the interest of naturalists from the earliest days of scientific enquiry and many of the basic principles of stratigraphical division and geological structure were established within them. As long ago as the late 18th century a threefold division of the Carboniferous rocks was recognised in northern England, based on lithological characteristics that are particularly well marked in Lancashire and the southern Pennines: the Carboniferous, or 'Mountain' Limestone at the base; the Millstone Grit; and the Coal Measures at the top. These lithostratigraphical (rock) divisions subsequently became broadly equated with the chronostratigraphical (time) divisions: *Dinantian*, *Namurian* and *Westphalian*, respectively:

- **Dinantian** (354 to 327 million years ago) is taken from the Belgian town of Dinant, where there are good sections of rocks of this age, mainly limestones, in the cliffs of the River Meuse. The term Dinantian has been superseded for formal use worldwide, but reference is made to it in this publication as it is essential for understanding existing descriptions of British Carboniferous rocks.
- **Namurian** (327 to 316 million years ago) is derived from the province of Namur in Belgium.
- **Westphalian** (about 316 to 306 million years ago) comes from Westphalia in north Germany.

The block and basin topography formed in early Carboniferous time persisted until the early

The distribution of Carboniferous rocks in the district



Namurian (p. 21). Much greater thicknesses of sediment accumulated within the basinal areas than on the intervening blocks; widespread marine limestones enable correlation between basins and blocks. The youngest Carboniferous rocks in Britain occur in the English Midlands and parts of northernmost England and southernmost Scotland, where a succession of reddened rocks (red-beds), in topmost Westphalian and overlying strata, represent the period from 306 to 290 million years ago.

The succession of Carboniferous rocks over much of Britain records the transition from the predominantly

marine conditions in the Dinantian to the almost exclusively freshwater deltaic environments of the Westphalian. The rocks contain abundant fossils which enable correlation of British strata with Europe and beyond. Britain has some of the best-exposed sequences of non-marine, upper Carboniferous strata anywhere in Europe.

Carboniferous rocks in the district

In Carboniferous times the district lay in the Northumberland Trough, bounded by two fault systems which influenced sedimentation: the North Solway Fault to the north and the Stublick–Ninety Fathom Fault to the south.

During Dinantian and early Namurian times over 2500 metres of shallow marine and deltaic deposits, derived from the north and east, were laid down in the Northumberland Trough. This is in stark contrast to the much thinner succession laid down south of the Stublick Fault, on the more buoyant 'Alston Block' (p. 21). The Namurian rocks typically comprise thick successions of shales, siltstones and sandstones with some, generally thin, beds of limestone and coals. 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 was eventually preserved as 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 altered the nature and maturity of coals.

It is likely that rocks of later Namurian and Westphalian age once covered the whole of the district but were later removed. Much of this erosion probably took place in the late Carboniferous and early Permian periods.

Dividing and classifying the Carboniferous succession

Rock successions can be divided and categorised in a number of different ways, including subdivision according

to the characteristics of the rocks themselves, zonation by the nature of fossils contained in the rocks, or correlation utilising a combination of both methods. Lateral variation in the nature of the Carboniferous rocks across Northumberland has long presented geologists with problems in attempting to correlate them across the county. In 1863, on the basis of the sequence in north Northumberland, particularly in the River Tweed, George Tate of Alnwick, proposed a simple fourfold division of the Carboniferous of northernmost England. Numerous subsequent surveys and publications have added to the complexity of the nomenclature and have, to an extent, tended to confuse matters rather than clarify them. Such a situation is not confined to Northumberland and, in order to clarify regional understanding, a lithostratigraphical scheme encompassing the Carboniferous rocks of the entire onshore of Great Britain has recently been adopted. Although not yet used widely on BGS maps these regional group names will be implemented in future publications. Accordingly, the description of Carboniferous rocks in the district follows these new divisions, listed below with the youngest at the top:

Pennine Coal Measures Group
Yoredale Group
Border Group
Inverclyde Group

The rocks of these groups are described below, starting with the oldest.

Inverclyde Group

The early Carboniferous succession of the Northumberland Trough, deposited along the southern margin of the Southern Uplands, is distinct from that being deposited in the remainder of England at the time, but very similar to that being deposited in the Midland Valley of Scotland. In recognition of this similarity, recent work has extended the Inverclyde Group and two of its component formations, the Kinnesswood and Ballagan formations, from Scotland into the northern part of the Northumberland Trough.

Kinnesswood Formation

At the base of the Carboniferous succession in the Kinnesswood Formation, locally-developed coarse conglomerates outcrop along the flanks of the Cheviot massif and represent the oldest deposits of the basin fill.

These include the Roddam Dene, Ramshope Burn and Windy Gyle conglomerates. Although initially thought to be part of the Old Red Sandstone, they are now generally accepted to be of basal Carboniferous age, despite the absence of diagnostic fossils. The best exposed of these, at Roddam Dene, comprises a mix of beds of conglomerate, sandstone, shale, mudstone and marl of various colours, but is dominated by massive reddish coloured conglomerates of subangular to subrounded, pebble-to-boulder sized clasts of Cheviot andesite with minor amounts of Palaeozoic sediments and rare Cheviot Granite set in a clay-rich sandstone matrix. It is interpreted as the product of ephemeral streams that drained the deeply eroded margins of a Cheviot landmass that was exposed to semi-arid weathering conditions in early Carboniferous times.

The Kinnesswood Formation is named from Kinnesswood, near Loch Leven in Tayside, Scotland, where it is a succession dominated by sandstones, typically with layers of white to pale grey dolomitic or carbonate nodules known as 'cornstones'. Cornstones form as a result of a fluctuating water table through the soils of semi-arid floodplains.

The Roddam Dene Conglomerates exposed in Roddam Dene



In Northumberland, such sandstones containing cornstones, for example those underlying the Cottonshope Volcanic Formation (p. 48) and found in the Redesdale valley, were previously assigned to the 'Lower Freestone Beds'. The sandstones are often coloured red or spotted with brown ochre, and associated with purple, lilac, green and red shales frequently containing ochreous concretions. In most of Redesdale the upper boundary between the Kinnesswood Formation and the overlying Ballagan Formation nearly coincides with the contemporaneous outflow of Cottonshope lavas.

**Ballagan Formation
(part of the former Cementstone Group)**

The formation is named from Ballagan Glen in the Campsie Fells, north of Glasgow. Used throughout Central Scotland for the mudstone, siltstone and cementstone sequence towards the base of the Carboniferous, the name is now also used in northern England to describe the continuation of that succession into the Northumberland Trough.

The Ballagan Formation outcrop forms a broadly arcuate pattern almost entirely surrounding the Cheviot volcanic rocks within the district. East of Chatton the formation is brought up in the core of the Holburn Anticline (p. 81). It is a sequence of interbedded cementstone, mudstone, limestone and sandstone that is of lagoonal and estuarine origin in the north, but becomes more marine when traced westwards towards Bewcastle. The relative proportion of the different rock types varies across the district and vertically within the formation, which has its maximum estimated thickness of over 600 metres to the south of the River Tweed. The beds range in colour from grey and blue-grey, through green and yellow to brown and pinkish red. The basal cementstones are interpreted as having been deposited in a lagoonal, coastal-flat environment under conditions of high salinity and periodic desiccation.

The cementstones of the district are broadly of two types. Layered cementstones have a sharply defined top and base and some may show signs of internal stratification. They may also have sedimentary features and desiccation cracks. Nodular cementstones show a transition into calcareous mudstones above and below and they form a more or less persistent layer or a row of nodules. The layered cementstones are thought to be

primary in origin and the nodular cementstones of secondary origin. The beds are generally less than 0.3 metres thick. The mudstones interbedded with the cementstones are calcareous, silty, poorly bedded and range in thickness from a few millimetres to several metres. Sandstones and siltstone also occur in the sequence and are very variable. Two exceptional limestone developments within the formation are worthy of note. Just south-west of Coldstream the Carham Limestone is a thick-bedded magnesian limestone up to 8 metres thick with a brecciated appearance. 1 kilometre south-west of Rothbury the disused, Glebe Quarry [NU 052 005] provides a section of limestone, some 6 metres thick, widely regarded as one of the finest developments of oncolitic ('algal') limestone of the British Carboniferous Period.

Influence on the landscape

The rocks of the Ballagan Formation are relatively soft and thus easily eroded by weathering and glacial action.

Mudstones and cementstones of the Ballagan Formation in Akenshaw Burn



Hence, much of the area they underlie forms low-lying ground and is now covered with Quaternary deposits. Consequently the landscape tends to reflect the nature of the overlying Quaternary deposits rather than that of the bedrock. In a few places, river erosion has exposed fine sections, such as the river cliff of the Coquet at Barrow Scar.

In the Kielder area, the Ballagan Formation produces smooth green slopes that contrast strongly with the adjacent rough heatherclad hills underlain by the Fell Sandstone. Good examples are seen at the Peel Fell escarpment and on either side of the White Kielder. The individual limestones of the formation do not, as a rule, form the prominent fresh green vegetation bands that other limestones in the Carboniferous do. This is probably due partly to their impurity and partly to their thinness which allows the outcrop to be readily covered by soil creep or drift. In places, for example near Otterburn where the top of the formation contains good limestone, sink holes are present at the base of the Fell Sandstone. Sandstones form the prominent knoll of Glanton Pike and the parallel escarpments that run between Whittingham and Alnham where evidence of quarrying can be seen.

Influence on biodiversity

The influence on biodiversity is varied and like the landscape linked more to the Quaternary deposits overlying the rocks. A lot of the outcrop of the Ballagan Formation occurs between Rothbury and Nethererton on the edge of the National Park and this is typified by small enclosed fields with some arable land. The biodiversity of the area is more linked to the management of this land and the features associated, such as hedges and field edges than the underlying rocks. Where the soils are derived from the bedrocks there may be some local influence, for example base-loving plants and fine grasses in limestone areas. In areas where there are thick mudstones, drainage is impeded and results in boggy ground dominated with rushes and grasses such as tufted hair grass.

Economic use

Many of the thicker limestone units 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. Remnants of the former small quarries and limekilns can still be seen marking the outcrop of the limestones. None of the limestones are worked today.

Many of the thicker and more robust sandstones have also been quarried throughout the district for building stones, but are no longer worked. Although these have been dominantly for local use, some quarries such as those at Greenlaw and Glanton Pike are known to have exported stone as far as Carlisle, Glasgow and Edinburgh.

Under present, or currently foreseeable, economic conditions it is unlikely that these rocks will attract significant commercial interest. Small scale reworking of some historic quarries may occur for matching stone in old buildings.

Wider significance

The Roddam Dene Conglomerate, arguably the finest of its kind in the British Dinantian succession, is critical to our understanding both of the early Carboniferous palaeogeography of the area and the development of the Northumberland Trough.

Geological SSSIs

Dinantian of northern England and North Wales

Glebe Quarry	[NU 052 005]
Roddam Dene	[NU 021 208]

Geological SNCIs

Akenshaw Burn, Barrow Scar, Caistron Ponds, Canker Cleugh, Catcleugh Burn, Crawley and Lincomb Denes, Dovecrag Burn, Fredden, Preston Yeavinger Bell, Glanton Pike Quarry, Horsdon Channel, Lumsdon Law, Thrum Mill Gorge.

Border Group

The Border Group of northern England and southern Scotland consists of two sedimentary formations, a lower, Lyne Formation and upper, Fell Sandstone Formation. However, in the east of Northumberland and throughout practically all the area of Border Group outcrop in the district, the Lyne Formation is absent and the Fell Sandstone directly overlies the Ballagan Formation. Further south and west, in the deeper parts of the Carboniferous Northumberland Trough, a thick Lyne Formation succession of sandstone, siltstone, mudstone and thin limestone underlies, or in its upper part replaces, the Fell Sandstone.

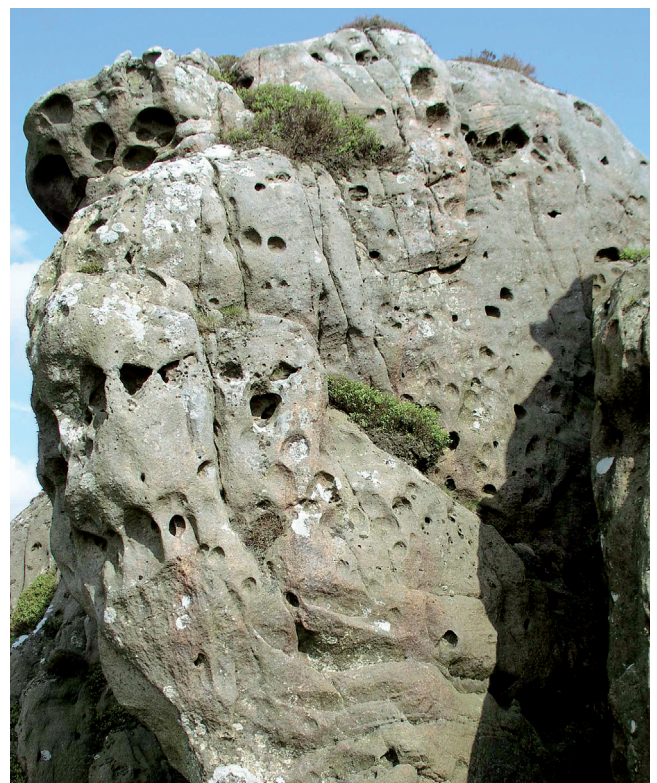
Lyne Formation

Lyne Formation rocks are present beneath superficial deposits in the very west of the district, but are nowhere exposed.

Fell Sandstone Formation

The name Fell Sandstone was introduced in the late nineteenth century to describe the characteristic sandstone-rich sequence of rocks exposed on the hills (or fells) of Northumberland. At outcrop it can be traced as a number of prominent sandstone crags and scarp faces, which run in an arcuate pattern from Berwick to Rothbury, thence westwards to Carter Fell, and finally southwards to the Gilsland area. The beds in general have a gentle dip of 5 to 10 degrees away from the Cheviot 'dome', but in the Holburn Anticline near-vertical dips occur (p. 81). Examination of the outcrops led many early workers to believe that the sequence consisted almost entirely of sandstone. This is indeed the case in parts of mid-Northumberland, notably around Rothbury and Harbottle, where the formation attains its maximum thickness of about 350 metres. However, the

The Fell Sandstone at Echo Crags, showing distinctive hollows produced by weathering of the sandstone



proportion of sandstone to shale varies considerably within the Northumberland Trough and boreholes show that in places the Fell Sandstone may contain up to 40% of finer grained lithologies.

Within the district the rocks are, in the main, very thick hard grits and moderately- to poorly-sorted, generally medium- to coarse-grained, but locally fine-grained, sandstones. In places sandstones overlie one another to form multistorey units up to 90 metres thick. They contain subangular to subrounded fragments of mudstone and a few pebble layers. The excellent sedimentary structures preserved include a variety of forms of cross-stratification, examples of steep-sided channels and thick structureless units. The succession is largely unfossiliferous, although ostracods and the large bivalve *Archanodon jukesi* (Bailey) have been recorded together with some plant fossils.

Influence on the landscape

The very thick hard grits and sandstones form the long tiers of crags and bold escarpments that are so

conspicuous in north Northumberland. They are distinctive skyline features characterised by generally level tops, scarp slopes, and craggy outcrops. The crags usually carry screes, and a hillwash of white sand is commonly conspicuous amongst the heather and wasting peat. In the north, the Fell Sandstone encircles the Cheviots in a belt which has a curious tendency to be duplicated by faulting. The outer ring is the more prominent. The outcrop culminates in the Simonside Hills, reaching 440 metres south-west of Rothbury. In spite of its modest elevation, this group of moors forms perhaps the most imposing feature in the county. In Upper Redesdale and Upper North Tynedale, the much afforested Fell Sandstone hills of Carter Fell, Peel Fell, Deadwater Fell and Glendhu Hill are bulkier and, rather than making cuestas, are tabular in form. In the Border country, between Carter and Peel Fells, the presence of a thick bed of soft water-logged marls has involved the overlying crags of grit in numerous vast landslides, the so-called 'stony holes' of that area. A number of caves are developed along the outcrop of the Fell Sandstone. The longest being Roughting Linn Cave [NT 982 368].

Bell heather growing on the coarse-grained sandstone crags at Dancing Green Hill, between Doddington and Belford



Influence on biodiversity

The silica-rich sandstone bedrock slowly weathers to form thin, acidic, nutrient-poor sandy soils which support heather moorland, particularly above 250 meters.

Heather, mainly ling, grows in extensive patches on much of the upper slopes and crags of the hills. Other associated dry heath species include bilberry, cowberry, crowberry, and bell heather (particularly on rocky outcrops). Species found on wet heath include cross-leaved heath, deer grass and hare's tail cottongrass. This moorland is managed both for grouse, and as rough grazing for sheep where it often forms an acid grassland/heather mosaic. Both the Simonside Hills and Harbottle Moors SACs, support excellent examples of both wet and dry heathland vegetation which occur in mosaic with blanket bog and raised mires and shallow loughs. Bog myrtle is found in wetter areas and some uncommon species such as dwarf cornel occur on ungrazed ledges. Breeding waders such as golden plover, curlew and dunlin are found together with crag nesting birds such as kestrel, raven and peregrine. The Grasslees Burn valley, which lies between the Harbottle Hills and the Simonside ridge supports remnant alder woodland and areas of semi-natural upland oak and birch woodland together with small areas of juniper scrub. The sandstone crags, such as Great Dour and Echo Crags, often have curtains of pendulous lichens hanging from vertical faces, including several species of *Usnea* and *Bryoria*, and most of the English population of *Alectoria sarmentosa*. Dry underhangs have pink patches of *Arthonia arthonioides*.

Economic use

Throughout much of its outcrop the Fell Sandstone has proved suitable for use as a building stone, although in some places the rock is too soft for use as a freestone. Sandstone quarrying continues today. Pebbly sandstones are sometimes gritty enough for millstones. Suitable 'grits' contain a proportion of comparatively softer grains, which ensures that the rock maintains a rough surface when exposed to wear and keeps its abrasive nature. Evidence of the quarrying and remains of partially-completed millstones can be seen near Harbottle Crags and on Beanley Moor. The digging of millstones on Harbottle Crag is mentioned as early as 1604 and continued until the 19th century.

The thickness, geometry and lateral persistence of the Fell Sandstone make it one of the few potential hydrocarbon reservoirs in the Northumberland Trough.

It is also a good aquifer because of continuity, thickness, high porosity through fractures, and low cementation.

Conservation

Fell Sandstone crags, including Simonside and Bowden Doors are popular for climbing. Climbers, in general, are well aware of the need to respect the rock faces and the British Mountaineering Council issues a code of good practice. There are opportunities to continue to work with groups to monitor and protect sites.

Wider significance

The Fell Sandstone is one of the most prominent and best-exposed rock units in the Carboniferous succession of the Northumberland Trough. Sedimentary features typical of fluviodeltaic alluvial plain sediments, with braided and meandering river bedforms are outstandingly displayed in the crags. The river system, flowing some 340 to 330 million years ago, may have been comparable in extent to the braided stretches of the modern Brahmaputra River in Bangladesh. The high quality of the sections has continued to invite a number of modern detailed interpretations of such depositional environments and sedimentology.

The Fell Sandstone is associated with a variety of prehistoric sites, which together form some of the most interesting archaeological landscapes in England. These include 'cup and ring' marked rocks, Bronze Age burial cists, earthwork remains of later Iron Age hill fort systems, standing stones, enclosures, and cairns.

Cup and ring marks in sandstone boulder from Powburn, now at Ingram Visitor Centre © NNPA



Geological SSSI

Dinantian of northern England and North Wales

Colour Heugh and Bowden Doors

[NU 066 337 to NU 070 326]

Geological SNCIs

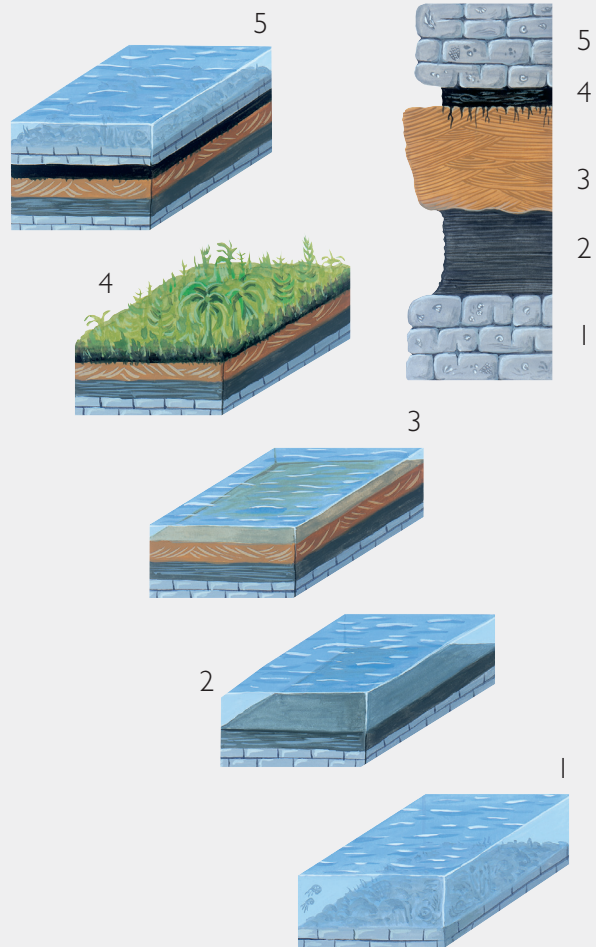
Akenshaw Burn, Bowden Doors, Callaly and Thrunton Crags, Catcleugh Burn, Coldmartin Loughs, Dovecrag Burn, Kyloe Hills, Shiellow Crags, Thrum Mill Gorge, NWT reserves Harbottle Crags.

Yoredale Group

The Yoredale Group consists of a cyclic succession of rhythmically deposited sediments. These are known as Yoredale cyclothem as Yoredale was the old name for Wensleydale in North Yorkshire where they were first studied. Each cycle ideally comprises, in ascending order, limestone, mudstone, sandstone frequently topped with seatearth, and locally coal. The cyclicity can be observed at a variety of scales and in varying degrees of complexity; the largest cycles occur at the scale of tens to hundreds of metres in thickness. The cycles have been interpreted as the products of alternating periods of relatively slow and rapid relative subsidence of the area, reflecting a complex interplay of marine and non-marine deltaic conditions during sedimentation. During periods of slow subsidence, deltas advanced across the area from the north carrying mud and sand. Periodically, deltas built up to above sea level allowing the growth of swamp forests now represented by seatearths and coal seams. With more rapid subsidence warm, clear marine water spread across the area, overwhelming the deltas and depositing marine limestone. Sea level changes related to repeated growth and melting of southern hemisphere ice-sheets may also have played an important role in the formation of Yoredale cyclothem.

Whereas many cyclothem include representatives of each rock type, others are incomplete with one or more of the characteristic rock units absent. Most commonly absent is the coal horizon. Limestones are the most persistent, and generally the most easily recognised, of the component rocks, although they commonly comprise only a comparatively small proportion of the total thickness of rocks within the succession. The limestones are generally rather impure and contain significant amounts of clay and bituminous impurities,

Yoredale Cycle



- 1 Shelly debris accumulated at the bottom of a shallow tropical sea. It eventually hardened to become limestone.
- 2 Mud carried into the sea by rivers draining from the north settled on top of the limestone. This became mudstone.
- 3 River deltas advanced into the sea, depositing layers of sand. This hardened into sandstone.
- 4 Swamps and rainforests grew on the top of the river delta. Their remains became coal seams.
- 5 The sea level changed, flooding the forests. Marine life returned and shelly debris covered the coal. And so the whole cycle started again.

Illustration © Elizabeth Pickett

giving them a rather dark grey colour. Most contain an abundance of, mainly fragmentary, fossils. Although certain beds are characterised by rich faunas of fossils such as corals and sponges, it can be extremely difficult or impossible to tell the limestones apart. By convention, each cyclothem is named after the limestone at its base.

Many individual rock units have long had local names, several of which can be recognised and correlated over wide areas. Many of these names recall the locality at which the rock unit is best developed, at which it was first distinguished, or reflect a variety of intrinsic characteristics such as thickness.

The Yoredale Group is divided into three formations, based largely on the relative abundance of the different rock types within the cycles of each division, from the bottom up these are the **Tyne Limestone Formation**, the **Alston Formation** and the **Stainmore Formation**. Limestones generally increase in importance and thickness as the sequence is traced up towards the top of the Alston Formation, and decline in significance thereafter.

Tyne Limestone Formation

All but the thinnest and most impersistent limestones in the formation are named and comprise useful correlative horizons. Between the limestones the succession, mainly comprising mudstones and sandstones, is much more varied in character and thickness from place to place. Immediately above the limestones, the mudstones are commonly fossiliferous and calcareous and pass upwards into dark grey or black rocks, in places with clay ironstone nodules. 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 mainly fine grained; coarse pebbly sandstones are relatively uncommon. North and east of Bellingham the lowest part of the formation, formerly known by the now obsolete name 'Scremerston Coal Group', contains a number of workable coals. Elsewhere, coal, if present, is rarely more than a few centimetres thick.

Alston Formation

Thick, commonly bioclastic, limestones are the most persistent and laterally extensive rock types within the formation. The Great Limestone at the top is up to 15 metres thick, other limestones rarely exceed 6 metres in thickness.

Stainmore Formation

A rhythmic succession dominated by shales and sandstones with a small number of interbedded thin limestones and coals dominates the Stainmore Formation. The limestones are typically only a few metres thick at most; towards the top of the succession they become fewer and much more impure, locally becoming difficult to distinguish from calcareous sandstones or mudstones. Many sandstones 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 freshwater or swamp environment. Over substantial areas of the central and southern Pennines, rocks of equivalent age to the Stainmore Formation mainly comprise thick successions of hard, coarse-grained sandstones to which the term 'Millstone Grit' is commonly applied. These sandstones give rise to the bleak moorlands and gritstone 'edges' of the central Pennines around Kinder Scout and the so-called Black Peak. Although used in some older

The Great Limestone and overlying shale at Greenleighton Quarry



Examples of rock units in the Yoredale Group

Tyne Limestone Formation

The Thirwall (Furnace) Coal and Bellingham (Plashetts or Carritheth) Coal, slightly lower in the succession, have been worked in many parts of the district. The Bellingham Coal forms a useful stratigraphical marker because numerous old adits, bell-pits and spoil heaps attest to its presence.

The Redesdale Ironstone Shale is well known in the geological literature for its profusion of well-preserved fossils, particularly bryozoans, brachiopods, bivalves and crinoids. The fossils are concentrated into layers sometimes preserved in ironstone. The 'shales' are some 9 metres thick, with subsidiary concretionary siderite nodules forming up to 10 per cent of the total sequence. These nodules, varying in size up to 35 cm, occur as scattered discontinuous concretions, locally coalescing to form irregular bands. They were formerly worked on a substantial scale as iron ores. Both the overlying limestone and the shale are now poorly exposed, one of the best localities being the Hareshaw Burn [NY 8425 8445 to NY 8420 8460] near Bellingham. The most distinctive horizon is the 'Shell Band', which occurs near the middle of the 'shales'. It was recognised by the miners and used by them to subdivide the beds into upper and lower 'plate' or 'shale'. The shell band is up to 25 cm thick and so rejected as valueless by the miners. It now

Ironstone nodules in the Redesdale Ironstone Shale at Redesdale



remains in large piles such as those in Sir William Armstrong's quarries near The Steel [NY 8955 8303] or scattered throughout the innumerable waste tips around Ridsdale and Bellingham [NY 886 842 and NY 843 841].

The Redesdale Limestone, a few metres above the shale, is usually well exposed and in the type area, near Ridsdale, has been extensively quarried. In Tipalt Burn [NY 7113 6960] near Wall Shield a bed, believed to be the Redesdale Limestone, contains corals and gigantoproductids.

The Fournalms Limestone, named from Fournalms Edge [NY 9123 8355] near Ridsdale, locally contains an abundant fossil fauna. The foundations of Chipchase Castle stand on the Fournalms Limestone.

The Fournalms Coal, one of the few economically important seams of the Dinantian, has been worked north of Barrasford at Hareshaw Head [NY 8454 8835] and at Elsdon. The coal was last mined near Gunnerton at Sully Row Colliery [NY 9053 7756], which closed in the 1970s. The workings were particularly wet, a feature of many of the small mines in this area.

Alston Formation

The Oxford Limestone, 5 to 6 metres thick, is seen in many natural and quarry exposures and is particularly rich in corals and brachiopods. It is a grey to dark grey limestone with numerous red weathering *Osagia* ('*Girvanella*') haloes and although *Osagia* occur in other limestones, they are rarely so obvious or in such rich abundance. In Barrasford Quarry the limestone is partly metamorphosed to marble adjacent to the Whin Sill.

The Barrasford Limestone ('Tynebottom Limestone') locally forms a prominent feature in which some relatively extensive quarries were formerly opened. Exposures are poor in the immediate area of the Roman Wall.

The Eelwell Limestone is a massive grey bioclastic limestone devoid of mudstone partings. It has been extensively quarried and is locally well exposed.

The Three Yard limestone is commonly crinoidal and with numerous mudstone partings. Clay ironstone nodules, an impure form of siderite, are locally common in the shales above the Three Yard Limestone and were quarried for iron in the 19th century near Cawfields.



Quarry in the Four Fathom Limestone near Milecastle Inn

The Four Fathom Limestone, a grey wavy-bedded and locally cherty limestone commonly forms a pronounced feature and is locally well exposed. Also known as the 'Eight Yard' throughout much of northern and central Northumberland, its name reflects its thickness of 24 feet (7.3 metres).

The Great Limestone (Catsbit Limestone, Dryburn Limestone) is one of the most extensive limestones within north-east England. The name, given to it by early lead miners and quarrymen, reflects both its thickness and economic importance. It is by far the thickest (up to 15 metres) and purest limestone within the district and has been extensively quarried along the length of its outcrop. Like the majority of the underlying 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. Some individual beds of limestone can be traced for several kilometres. Three major divisions of the limestone have been recognized throughout the district.

The lowest few metres are commonly dolomitic and include the distinctive Chaetetes Band (p. 85). The middle division, 5 to 6 metres thick, sometimes called the 'Main Posts' is composed of grey, wavy-bedded, fine-grained limestone with few large (macro) fossils. It contains the Brunton Band. The topmost division, up to 7 metres thick, 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.

Chaetetes Band in Great Limestone at Brunton Quarry



Stainmore Formation

The Little Limestone Coal, underlying the Little Limestone, is the thickest and most consistent in the formation and has been extensively worked from numerous mainly small mines between the western extremity of the district and Haydon Bridge, most recently from Blenkinsopp Colliery, and in the Fourstones and Acomb areas.

The Little Limestone is a persistent bed proved in many boreholes but rarely seen at outcrop.

geological literature, the use of the term 'Millstone Grit' for the Northumberland sandstones is today considered inappropriate as they do not generally exhibit the same lithological characteristics and were not deposited in precisely the same environment.

Influence on the landscape

Because of their extensive outcrop the rocks of the Yoredale Group are of fundamental importance in shaping the landscape and giving the district its distinctiveness. Glacial action and weathering of the alternately hard and soft beds within well-developed Yoredale cyclothem, particularly of the Alston Formation, 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. Such terraced hill slopes are conspicuous in many parts of the district, especially around Hadrian's Wall, in the upper parts of the North Tyne valley and

around Otterburn. Hareshaw Linn, near Bellingham, is a spectacular waterfall formed by a thick sandstone. The Stainmore Formation outcrop is much concealed beneath superficial deposits, though a number of prominent sandstones give rise to distinctive ridge-like features. Conspicuous examples of sandstone crags include those of Great Wanney, Hepple Heugh, Darney Crag and Lunga Crags in the West Woodburn area and King's and Queen's Crags near Hadrian's Wall. Sink holes locally mark the outcrop of the thickest limestone units, most notably the Great Limestone, but other examples of these may be seen near the A68 south of Ridsdale.

Mining and quarrying have left their mark on the landscape. The large scale working of sandstone for building stone has left substantial quarries on the hillsides around West Woodburn, and Otterburn. Relatively large quarries in the Great Limestone can be seen in the south of the district. Large scale extraction of iron ores around Ridsdale and Bellingham has left a conspicuous legacy of abandoned quarries and spoil heaps; adit mouths are still visible near Ridsdale [NY 9019 8409] and Bellingham

Limestone, mudstone and sandstone of a typical Yoredale cyclothem exposed in Hareshaw Linn, Bellingham



[NY 8438 8401]. Innumerable small pits for walling and building stone, and for lime burning, are scattered across the district.

Remains of coal mining are on a modest scale. Small but obvious grey spoil heaps remain to mark the site of several mines in the Bellingham, Rochester and Longframlington areas. Extensive areas of outcrop workings and shallow bell pits can still be traced on the Fourlaws Coal in Redesdale, particularly around and across the Otterburn Ranges.

Influence on biodiversity

Outcrops of shales or sandstones, especially in the Alston Formation, where substantially free of superficial cover, typically give rise to neutral to acid soils which support extensive areas of acid grassland and heather moor. However, the undulating areas of this ground north of Hadrian's Wall have also been the site of peat development which has had a more profound influence on the vegetation.

Although limestones comprise only a comparatively small proportion of the district's geological succession, their outcrops may be distinctive. Outcrops of limestone, where free, or substantially free, of superficial cover, typically support areas of species-rich limestone grassland. The brighter green vegetation on the limestone, stands out from the whiter vegetation of the more acidic soils developed on the intervening mudstones and sandstones, and may be a useful clue to identifying limestone outcrops. Typical species include eyebrights, salad burnet, thyme, rock rose and fine grasses such as quaking grass and bents and a variety of small sedges. Quarrying, especially 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. Weathered limestone, in natural outcrops and abandoned quarries, provides extremely important habitats for a number of specialised plant communities, including as a substrate for ferns, lichens and other lower plants. Where limestone dissolution has taken place by natural groundwaters, emergent springs may carry a substantial amount of calcium in solution. Such springs may be associated with the development of tufa mounds and terraces in which calcite deposition may in part be facilitated by the influence of bacteria or algae. At least one calcareous spring near Kielder is associated with the development of flattened ovoid oncolites of algal origin.

Calcareous springs may also raise the pH of stream or pond water and the surrounding wet grassland supports species such as devil's bit scabious, grass of Parnassus, butterwort and fragrant orchid.

Both limestones and sandstones locally form areas of small bare crags and may provide important habitats for a variety of plants. Natural crags, cliffs and quarry faces may offer important nesting and roosting sites for birds and possibly bats.

The bulk of the Stainmore Formation 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* and *Molinia* grassland, known locally from its distinctive pale colour in the winter months, as 'White lands'. Again Quaternary deposits, particularly peat deposition, influence the biodiversity more locally.

Economic use

Rocks of the Yoredale Group have yielded a wide range of mineral products including limestone, coal, ironstone, sandstone and fireclay.

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. Large scale extraction of limestone within the district has been confined to the Great Limestone. Significant quarries were worked at Fourstones, Brunton, Ryal and Greenleighton. The Great Limestone is today worked on a large scale at Mootlaw Quarry; mainly as a source of crushed rock aggregate and as armour stone for coastal defence work. Metamorphosed Oxford Limestone is worked alongside Whin Sill dolerite at Barrasford Quarry and combined with the dolerite in certain aggregate mixes.

The coal seams of the Alston and Tyne Limestone formations are generally thinner and less laterally extensive than those of the Stainmore Formation and overlying Coal Measures, but coal has been mined, mainly from shallow underground workings, throughout the Yoredale Group. Output was largely for local domestic use, though significant amounts of locally

produced coal were employed in iron smelting at Ridsdale and Bellingham. The (Bellingham) Plashetts Coal was extensively worked for the Duke of Northumberland's tenants from at least the 18th century, from bell pits near its outcrop on Plashetts Moor. The Thirlwall Coal was worked near Thirlwall Castle, and on a rather more extensive scale at Robin Rock Drift (Ventners Hall Colliery) until the late 20th century. An opencast mine working a seam probably equivalent to the Thirlwall Coal, was operated at Briedge near Bellingham between 1984 and 1988. Thin coal seams within the Alston Formation beneath the Three Yard and Four Fathom limestones were mined on a small scale in the vicinity of Housteads and Cawfields. Commercial interest centred on the Little Limestone seam, which was mined extensively in the south of the district until the closure of Blenkinsopp Colliery in 2004. The seam was worked opencast at Melkridge from 1975 to 1977. A thin coal above the Oakwood Limestone was once worked from a small colliery in Haltwhistle Burn.

Rocks of the Alston Formation exposed in Prudhamstone Quarry, which provided high quality sandstone for many prestigious buildings in northern England during the second half of the nineteenth century



Although many mudstones in the Yoredale Group contain ironstone nodules it was only at restricted horizons that the nodules were big enough and sufficiently concentrated to warrant economic extraction. Roman iron smelted from the Redesdale clay ironstone deposits has been reported from Corbridge. Ancient bloomery sites in the Grasslees valley date from the 13th/14th century. Rows of clay-ironstone nodules (locally called "catheads") in the Lewis Burn were collected and smelted in the nineteenth century. Ridsdale and Bellingham were thriving centres of mining in the 19th century obtaining ironstone from the Redesdale Shales, the largest nodule recovered was reported to weigh 23 kg. Clay ironstone nodules in the shales above the Three Yard Limestone were also quarried in the 19th century, in Brackies Burn, north-west of Vindolanda and on Cawfields Common. Ironstone was also worked near Brinkburn.

Many of the sandstones have been exploited as building stones from an early date, current working quarries include Cop Crag, within the National Park (p. 95).

The mudstone and seatearth associated with some coals were worked as brick and pottery clays including at Haltwhistle, Bardon Mill and Langley in the south and Plashetts in the north.

Gilsland, in the extreme west of the district was, during the 18th and 19th centuries, a watering place and spa resort, based around the sulphurous and chalybeate (iron-rich) springs, which arise from pyritous shales in the Alston Formation rocks in the southern end of the Gilsland gorge of the River Irthing.

Extraction of the Great Limestone at Mootlaw Quarry is likely to continue. Future interest in iron ore working is extremely unlikely. Although there are reserves of coal probably suitable for further small-scale workings by both deep mining as well as by opencast methods, the thinness, variability and generally poor quality of the seams make it unlikely that any large scale working of these coals can be envisaged in the foreseeable future. The extraction of good quality building stone may be expected to continue from existing working quarries. Increased demand for, and popularity of, natural stone as a construction material and for repairs to existing stone structures may lead to interest in further working of previous deposits, or the search for new quarry sites.

Environmental and conservation issues

Most of the exposures of, and features associated with, these rocks are robust elements in the landscape. However, the *cuesta* landscape in the Hadrian's Wall area is especially noteworthy and suitable vigilance should be exercised to ensure that no operations or activities pose threats to it.

The progressive deterioration of long-abandoned quarry faces and the risk of quarries being filled and obliterated pose some long-term threats. A number of important sections through parts of the succession, including the type localities at which geological units were first named, are still exposed in abandoned quarries and might provide opportunities for interpretation or enhancement. Although some of these are scheduled as SNCIs, most are not currently managed and the local RIGS group could consider the possibility of taking responsibility for ensuring their continuity. Appropriate sections could be made accessible to educational groups or the public.

These early mining landscapes, together with the fragments of more developed later ventures, serve to remind us of the smaller scale coal workings landscapes of the Great Northern Coalfield which have been largely destroyed through land reclamation. This rarity significantly enhances the importance of the remains within the district.

Whereas many of the former underground coal workings are almost certainly flooded, discharges of contaminated mine water are not thought to present a widespread environmental problem. Small surface discharges of iron- and aluminium- rich water are present locally, for example in parts of Haltwhistle Burn and in the Crindledykes area. Although no instances of surface discharges of mine gases are known within the district, vigilance should be maintained for these close to buildings or centres of population. Few examples of ground stability problems over underground coal workings are known in the district. However, as many of these workings employed pillar and stall extraction methods, vigilance should be maintained for evidence of pillar failure and related stability problems.

Wider significance

These rocks provide a wealth of evidence of the geological environments and processes involved in their deposition during Carboniferous times. They provide

excellent illustrations of the effects of blocks and basins, and the structural factors which controlled their formation and evolution, on sedimentary facies and the thickness of sediments deposited. Comparison of this district with adjacent sedimentary basins, such as the Midland Valley and Craven basins, allows correlation of rock units to further understanding of the UK's evolution during Carboniferous times.

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 Chaetetes Band, exhibits striking examples of complete marine ecosystems fossilised *in situ*.

Geological SSSIs

Dinantian of northern England and North Wales

Redesdale Ironstone Quarries [NY 895 833]

Tipalt Burn [NY 659 661 to NY 687 683]

Namurian of England and Wales

Brunton Bank Quarry [NY 928 698]

Greenleighton Quarry [NZ 034 920]

Geological SNCIs

Tyne Limestone Formation:

Akenshaw Burn, Bowden Doors, Chirdon Burn, Colster Cleugh, Conshield Back Wood, Forest Burn, Hawkside South, Hawthorne Moss, Kyloe Hills, Linkleylaw Quarry, Mill and Whiskersfield Burns, Ridsdale Quarries, Shiellow Craggs, Swallow Craggs and Caw Burn, The Wanneys and Aid Moss, Warks Burn

Alston Formation:

Barmoorhill Quarry, Barras Quarry, Toddle, Reaver, Cawfield Craggs, Divethill and Claywalls, Forest Burn, Fourstones and Park Shield Quarry, Haltwhistle Burn, Milestone House Quarry, Walltown Quarry and Craggs

Stainmore Formation:

Haltwhistle Burn, Milestone House Quarry, Fourstones and Park Shield Quarry

NWT Reserve

Crindledykes

Pennine Coal Measures Group

A string of Coal Measures outliers extends westwards from the main Northumberland and Durham Coalfield along the south side of the Tyne valley. These areas provide a link between the major coalfields of Northumberland and Durham in the east and Cumbria in the west. These outliers are mostly elongated east-west and are preserved on the northern and downthrown side of a series of en-echelon faults that form part of the Stublick–Ninety Fathom Fault System (p. 80). The Midgeholme coalfield, with an area of six square miles, is the largest and the most westerly of the outliers. Only the easternmost part of this coalfield and small portions of the Plenmeller and Stublick coalfields are exposed at the very southern margin of the district.

Coal was being raised from Midgeholme itself as early as 1628. East of Midgeholme, in the Featherstone and East Coanwood areas, there are no records of early coal working, but collieries in these places were actively producing during the latter half of the 19th century. It was common practice for miners to give local names to the seams they worked and it was not until the geological survey of the Brampton district from 1923–7 that it was demonstrated that the sequence worked at Midgeholme could be correlated not only with that of the outliers to the east, but more significantly, with the sequence of the main Northumberland and Durham Coalfield.

Impact on the landscape

No mining in Westphalian rocks is now taking place in the district, but evidence of previous mining activity is seen in collapsed land, local concentrations of old bell pits, abandoned shafts and adits and spoil heaps.

Impact on biodiversity

An extensive mantle of Quaternary deposits, mainly glacial 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. Only a limited amount of opencasting has taken place in the district and special measures were taken at Plenmeller to minimise disruption to wildlife and habitats and to preserve peat deposits.

Economic use

In addition to deep mining in the small coalfields, opencast extraction took place at Plenmeller and

Melkridge in the late 1980s and early 1990s. Coal Measures mudstones and seatearths were commonly worked as brick-clays, as by-products of coal mining. It is likely that 'common' bricks were produced from such materials at the collieries in the Tyne valley. In the present economic climate a renewal of interest in the opencast coal potential of the district seems unlikely.

Wider importance

Exposures within the district are insignificant by comparison with the extensive coastal sections of Northumberland. However, the Westphalian outliers are important as examples of fault-bounded coalfields and help to define and demonstrate the geological structure of northern England. In addition, the sequence of Westphalian rocks present in these outliers provides important evidence linking the Cumbrian, Northumberland and Durham coalfields. The Stublick–Ninety Fathom Fault System was exposed and recorded during the excavation of the Plenmeller Opencast Coal site. Stublick Colliery is one of the best surviving 19th century collieries in the country. The coal names themselves provide a fascinating avenue for study and interpretation.

Stublick Colliery, Langley, at the southern margin of the district; one of the best surviving 19th century collieries in England



Igneous rocks

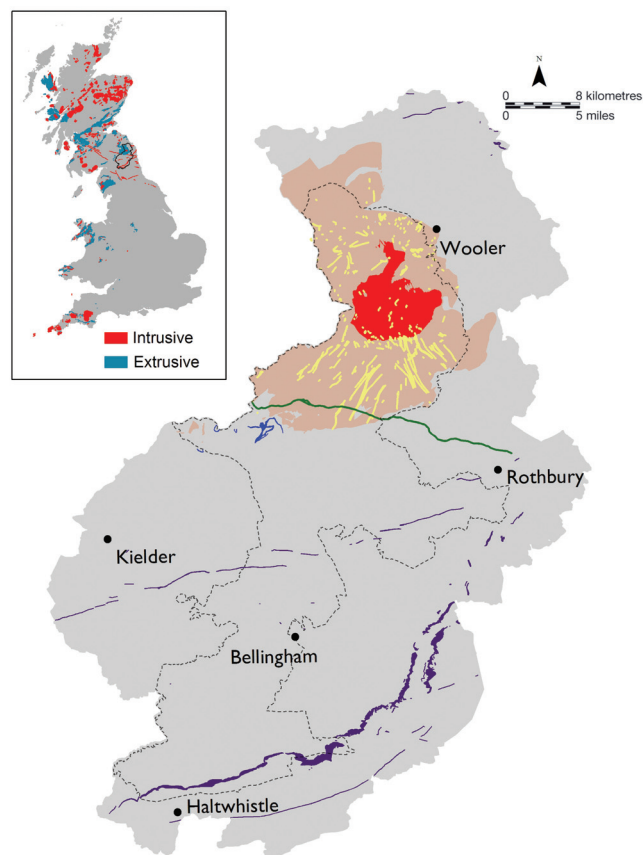
Igneous rocks crystallise from molten rock, or magma, generated within the Earth's mantle or crust. The buoyant magma rises and much of it may be intruded into rocks at higher levels in the crust to cool and crystallise as igneous intrusions. Large bodies of magma cool slowly forming coarsely crystalline rock such as granite, whilst smaller masses typically cool more quickly to form finer grained rocks. Kilometre-scale intrusions, with a rounded outline on the map, are referred to as plutons. Sheet-like intrusions that are mainly concordant with bedded sedimentary strata are called sills, and those that cross-cut strata are called dykes. Magma may also reach the surface at volcanoes, where it is erupted as lava or ejected explosively as fragments (including volcanic ash and volcanic bombs) that ultimately form pyroclastic rocks. Igneous rocks may be classified based on their silica content: those with low silica, for example basalt and dolerite, are termed basic rocks, whereas those with abundant silica, such as rhyolite and granite, are acid. Intermediate compositions include andesite and trachyte. Examples of all of these compositions and forms of igneous rock are represented within Northumberland National Park.

Igneous rocks in Great Britain

Igneous rocks with a range of compositions, forms and ages have played a significant role in the geological evolution of Great Britain and are exposed in many areas. Erosion during millions of years has exposed the igneous rocks at the surface today and careful study of them provides information both on the contribution these rocks have made to our geological evolution, and to the chemical and physical processes that have operated deep within the Earth throughout its history. Analytical techniques can be employed to determine the date of crystallisation of minerals within these rocks and hence the age of their formation. Interpretation of these dates, alongside other geological evidence, provides a method of assigning absolute dates to key events in geological history.

Most of the igneous rocks in Great Britain were emplaced during four major events: the Caledonian Orogeny, associated with closure of the Iapetus Ocean from late Cambrian to late-Devonian times; the Variscan

The distribution of igneous rocks in the district



Intrusive igneous rocks

Cainozoic 'Tertiary'		Acklington Dyke
Early Permian - Carboniferous		Whin Sill-swarm and associated dykes
Devonian	}	 Cheviot Dyke-swarm
		 Cheviot Granite Pluton

Extrusive igneous rocks

Carboniferous		Cottonshope Volcanic Formation
Devonian		Cheviot Volcanic Formation

(or Hercynian) Orogeny, associated with closure of the Tethys Ocean from mid-Devonian to early Permian times; crustal stretching during the Carboniferous and Permian periods; and crustal stretching prior to, and associated with, opening of the North Atlantic Ocean from the end of Cretaceous times to the present day. Older igneous activity is also recognised within Precambrian rocks.

Igneous rocks in the district

Igneous rocks contribute substantially to the geodiversity of Northumberland and give rise to two of the most impressive landscapes of the district, namely the Cheviot Hills in the north and the Hadrian's Wall country in the south. The Cheviot Hills are constructed almost entirely of igneous rocks, both volcanic and intrusive, that were emplaced during Devonian time, towards the end of the Caledonian Orogeny. By contrast, igneous rocks in the south of the district were intruded into the Carboniferous sedimentary rocks during the episode of crustal stretching that lasted from Carboniferous to Permian times. Some representatives of the latest igneous episode, associated with the opening of the North Atlantic Ocean, are also present within the district, particularly in the north.

Igneous rocks in the Cheviot massif

Igneous rocks in the north of the region belong to three of the major events outlined above:

- The *Cheviot Volcanic Formation* of Devonian age
- The *Cheviot Granite Pluton*, of Devonian age
- Various dykes and minor intrusions of Devonian age
- The *Cottonshope Volcanic Formation* of early Carboniferous age
- Cainozoic ('Tertiary') dykes

Cheviot Volcanic Formation

The Cheviot Volcanic Formation comprises a succession of lavas with intercalated pyroclastic and sedimentary rocks. It is poorly exposed over an area of about 600 square kilometres and its thickness is about 500 metres. The original thickness of volcanic rocks probably exceeded 2000 metres, making the Cheviot volcanic eruptions comparable in size to the late Ordovician volcanic rocks in the Lake District which record one of the most violent volcanic episodes in our history. The volcanic rocks unconformably overlie steeply dipping, tightly folded sandstone and cleaved mudstone of the Silurian Riccarton Group and are overlain by either Upper Old Red Sandstone Group conglomerates containing abundant andesite and granite clasts, or by lower Carboniferous beds, only some of which contain andesite fragments.

The basal unit of the formation in the south-west of the outcrop is well exposed in a rocky slope above the River Coquet, between Makendon and Fulhope [NT 8111 0992]. Here, about 60 metres of breccia are

composed of angular to subangular blocks of rhyolitic volcanic rock along with some mudstone fragments. Intercalations of pyroclastic and volcanoclastic sedimentary rocks are present higher in the succession, though they are sparse. Fragments of green fine-grained sandstone and siltstone are commonly seen in streams suggesting that this lithology is more common in the succession.

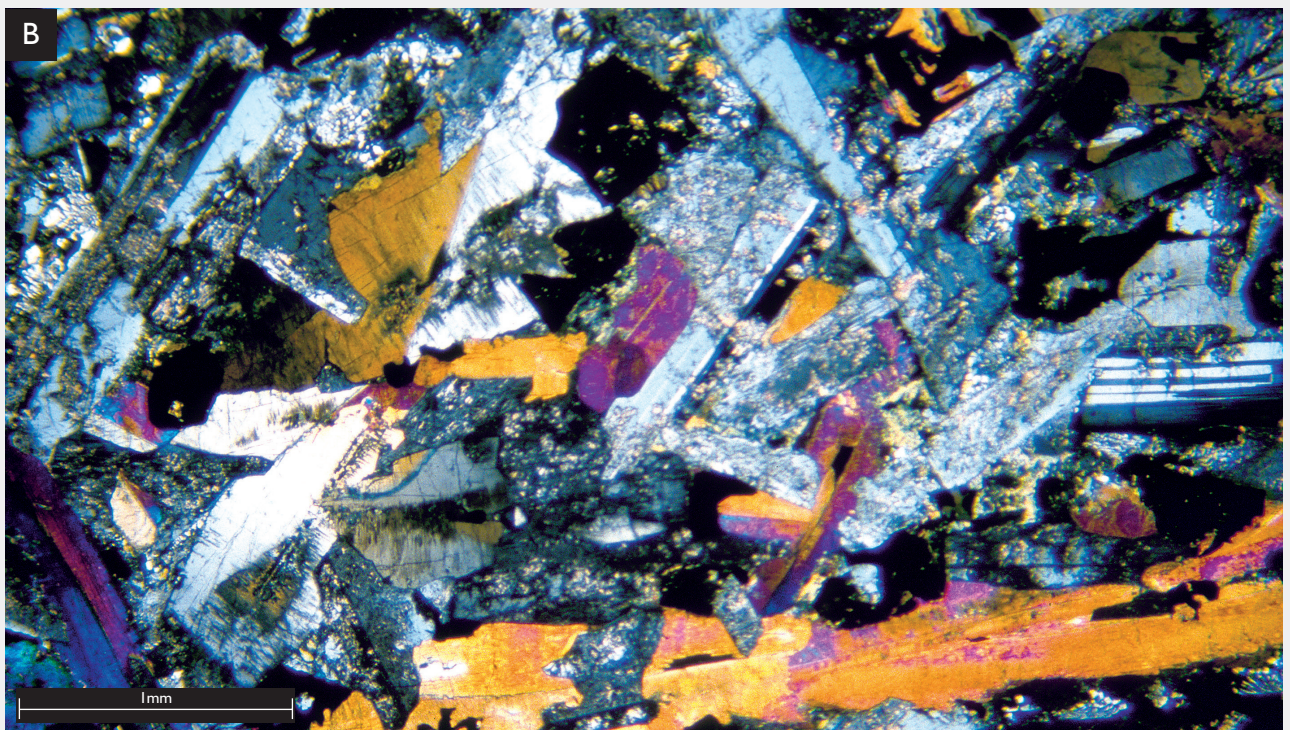
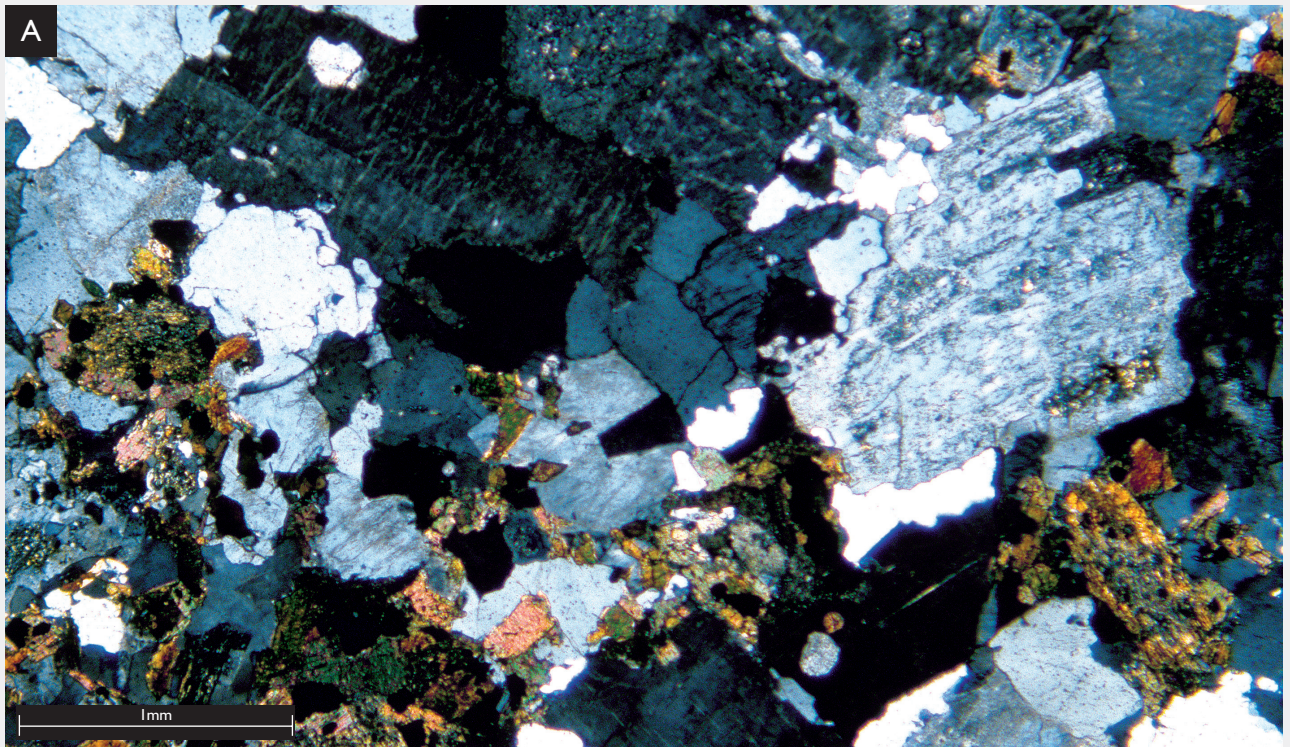
The lavas are andesitic and rhyolitic in composition and contain a variety of phenocrysts. There are also a few sheets of trachyte (previously described as 'mica-felsites') containing phenocrysts of biotite and feldspar. Many original features of the lavas are well displayed in the roadside exposure alongside the River Coquet. These features include irregular accumulations of blocky fragments on the top of the lava that formed as it flowed. Abundant amygdales that occur near the top of the lavas were originally gas or steam bubbles (vesicles) frozen in the lava and filled later with minerals such as calcite. Flow banding and platy jointing, characteristic of the central parts of the lavas.

A section through a thin lava, resting on an irregular surface cut in the underlying lapilli-tuff (volcanic ash) is well exposed at Blindburn [NT 8298 1079] in the upper Coquet valley. The more readily weathered pyroclastic and sedimentary rocks between the lavas have been eroded in some areas to form a prominent bench and scarp landscape. The benches reflect the gentle eastward dip of the sequence.

Fossils have not been found in these rocks. The lavas are thought to have been erupted in a subaerial setting though some of the sheets may be sills, intruded at shallow levels within the volcanic pile. There is no evidence that the volcanoes were like the classic conical structures such as those seen in the Andes of South America, rather there were probably a cluster of smaller volcanoes with gentle slopes. The radiometric age of about 396 million years determined on these rocks indicates that volcanism occurred in mid-Devonian time.

Over parts of the outcrop the volcanic rocks are completely weathered to a clay deposit, which in parts may be more than 10 metres thick. The primary igneous textures are preserved, indicating that the alteration occurred *in situ* (p. 69).

Photomicrographs of thin sections of igneous rocks taken under crossed polarizers



A – Granitic rock from the Cheviot Pluton. The speckled grey mineral is feldspar, the smaller irregular white and grey mineral is quartz and the brightly coloured minerals are mica (biotite) and a small amount of pyroxene. B – Pegmatitic dolerite from the Whin Sills: the brightly coloured mineral is pyroxene, the grey mineral is plagioclase feldspar and the small black grains are an iron oxide

Cheviot Granite Pluton

The Cheviot Granite is a broadly conical-shaped pluton that forms the central core of the Cheviot massif. The pluton has an outcrop of about 60 square kilometres, and a diameter of nearly 20 kilometres at a depth of 4 kilometres. Several phases of intrusion emplaced a suite of grey, pinkish grey and pink granitic and related rocks. In addition to the typical minerals associated with granitic rocks (quartz, orthoclase, plagioclase and biotite) some pyroxene is also present, and this is a rare feature of rocks of this composition in Great Britain.

The Cheviot Granite was intruded into the surrounding Cheviot volcanic rocks, with which it is considered to be related, about 395 million years ago in mid-Devonian time. At the pluton margin, in Common Burn [NT 930 265] and Hawsen Burn [NT 953 225], granite penetrates the adjacent volcanic rocks in a complex of dykes and veins, providing an insight into how this large igneous intrusion was emplaced. The volcanic rocks were thermally metamorphosed, in places up to 2 kilometres away from the contact (p. 54).

In this upland moorland region the granite is poorly exposed, except in some valleys and on the tors, such as Little Standrop and Great Standrop, for which the region is renowned (p. 69). A notable feature is the preservation locally of deeply weathered granitic rock. Here, grains of quartz are set in a matrix of clay minerals derived from the complete alteration of the original feldspar, biotite and pyroxene crystals. The original igneous texture is preserved, indicating that the alteration occurred *in situ*.

Devonian dykes and minor intrusions

A swarm of rhyolitic and trachytic dykes was intruded into the volcanic rocks and granite during Devonian time. These dykes form an impressive radial pattern centred on the granite, which together with compositional similarities to the granite and volcanic rocks suggests that they all belong to the same event. The reddish colour of the weathered surface of many of the dykes, compared with the grey or purple of the volcanic rocks, has enabled some to be traced for several kilometres across country. The dykes are typically up to 10 metres wide, but one example, exposed in the River Coquet, near Kateshaw Crag [NT 8794 0784], is at least 30 metres wide.

A distinctive red porphyritic rhyolitic rock, allied to the above dykes, crops out on the southern margin of the Cheviot Hills near Biddlestone [NT 961 084] and is extracted at Harden Quarry. This intrusion has been interpreted as a laccolith, a body of igneous rock that is roughly concordant with the strata into which it is intruded, but which has a planar base and a domed roof.

Cottonshope Volcanic Formation

The Cottonshope Volcanic Formation is a thin succession of basaltic lavas, that represents the only exposed record of volcanic activity associated with development of the Northumberland Trough in early Carboniferous time. The lavas crop out in a handful of localities south-west of the Cheviot massif, including Spithope Burn [NT 760 050], Hungry Law [NT 747 062], and between the Baseinghope Burn [NT 700 045] and the Chattlehope Burn [NT 730 028]. They are thickest and best exposed in the valley of the Cottonshope Burn, in Upper Redesdale [NT 803 058].

The upper part of the Cottonshope valley provides a complete section through the lava succession. There, lower Carboniferous strata dip about 10° to the south-south-west or south. The lowest basalt is underlain by sandstone and mudstone of the Kinnesswood Formation. The volcanic rocks are overlain by rocks belonging to the Ballagan Formation.

Three basalt lavas comprise the volcanic succession, the lowest two are exposed in a small road-metal quarry. The lowest is 12 metres thick and has an undulating scoriaceous (fragmented and clinkery) top containing pockets of sandstone. This is overlain directly by vesicular basalt, 6 metres thick. The uppermost basalt is also 6 metres thick, but is separated from the underlying ones by 6 metres of bedded mudstone, flaggy sandstone and 'cementstone'. The basalt contains small phenocrysts of olivine.

The lavas were probably erupted at approximately the same time as other basaltic lavas and intrusions from Central Scotland south to Derbyshire, including the Birrenswark and Kelso lavas in the nearby Southern Uplands, and the Cockermouth lavas in north Cumbria.

Cainozoic ('Tertiary') dykes

The rocks of northern England are cut by numerous basalt and dolerite dykes trending approximately



Outcrops of the Acklington Dyke in the River Coquet at Dumbhope

east-south-east. The distinctive magnetic signature of these dykes reveals that they belong to a swarm of dykes that emanated from the large volcano centred on the Isle of Mull approximately 58 million years ago in Paleocene times. The orientation and composition of these Cainozoic dolerite dykes distinguishes them from the late Carboniferous dykes associated with the Whin Sill-swarm. At outcrop many, but not all, of the Cainozoic dykes contain small but conspicuous phenocrysts of plagioclase.

Some of the dykes are impressive in their length. The most prominent of this suite of intrusions in the National Park is the Acklington Dyke which intrudes Silurian to Carboniferous rocks from the Scottish Borders through Northumberland and into the North Sea. Small exposures of this dyke may still be seen in the River Coquet [NT 8646 0864], east of Dumbhope, and in the Cartington area. At Acklington the dyke was reported to be up to 10 metres wide.

Though the dykes individually appear not to be very significant, collectively they were derived from a huge

volume of magma. It has been estimated that the Cleveland Dyke, seen to the south-west from Cumbria to North Yorkshire, represents a volume of at least 85 cubic kilometres. Numerical modelling of this dyke suggests that it emanated in a single pulse from a magma reservoir beneath Mull at a velocity of up to 18 kilometres per hour, reaching its furthest point in less than five days.

Igneous rocks in the centre and south of the district

The igneous rocks of this region are entirely intrusive into the Carboniferous succession. They belong to the Whin Sill-swarm and were associated with contemporaneous dykes that were emplaced during late Carboniferous to early Permian times.

Whin Sill-swarm and associated dykes

The group of four dolerite sills that comprise the Whin Sill-swarm has a roughly arcuate outcrop that extends across northern England from the Farne Islands in the north, south to Lunedale in the North Pennines. Three of these sills are present in Northumberland, the best known being the Great Whin Sill. From their surface outcrop, the sills dip gently to the east, south-east and south, more or less concordantly with the Carboniferous rocks into which they were intruded. Overall, these intrusive igneous bodies underlie more than 4500 square kilometres of northern England and beyond, beneath the North Sea.

The sills were intruded during late Carboniferous to early Permian times, probably between 301 and 294 million years ago. At this time, the rising Variscan mountains across mainland Europe and southern Britain, coupled with the reconfiguration of the Earth's tectonic plates far to the east, caused the crust in the area of what is now northern England, the Midland Valley of Scotland and parts of the North Sea to be stretched and ruptured. The rupturing allowed huge volumes of magma (at least 215 cubic kilometres in northern England alone), derived from the Earth's mantle, to be intruded between the layers of pre-existing sedimentary rocks at relatively shallow depths beneath the contemporary surface. The intrusion of such large volumes of molten rock, at temperatures of 1100°C or more, affected the adjacent rocks, baking and altering them (p. 54).

Though the sills are broadly concordant with bedding in the sedimentary rocks into which they were intruded, each sill is up to 50 metres thick in Northumberland, and

saucer shaped, rising by a series of steps to higher stratigraphical levels towards their outer extents. Whereas in much of the outcrop the sills occur as single sheets, east of Throckrington at least two, and in the Kyloe Hills up to five, separate sheets are present at different stratigraphical horizons. The change in stratigraphical level is best illustrated by the geological maps of the region, though small-scale changes in level can be seen at outcrop, for example at Cawfield's Quarry.

The sills are characterised by features that are typical of sills worldwide. Locally, for example at Barrasford Quarry, narrow, dyke-like masses of dolerite protrude from the upper surface of the sill into the overlying strata. At the base of the sill in places, the underlying sedimentary rocks have been levered up into the sill during intrusion; this is seen for example at Howick Quarry. Also, fragments of sedimentary strata ranging in size from just a few centimetres to several tens of metres ('rafts'), have become detached to 'float' within the body of the sill, as seen at Barrasford and Longhoughton quarries. Columnar joints, developed during cooling of the intrusion, occur in many natural exposures and in quarries, for example at Sewingshields and Walltown.

The dolerite is a dark greenish grey rock in which individual constituent minerals are visible with the aid of a hand lens. Close to the sill contacts with the surrounding sedimentary rocks, the magma chilled rapidly, resulting in a very fine-grained or almost glassy rock. Irregular patches and veins of coarser grained, pegmatitic dolerite, characterised by clusters of long, feathery pyroxene crystals, and of fine-grained pink (aplitic) rock, are rare in Northumberland, though the former rock type has been observed recently in Keepersfield Quarry [NY 896 727] and the latter from Barrasford Quarry [NY 910 742]. Spherical cavities (vesicles) up to 0.3 metres across, but generally smaller, are a common feature just beneath the top contact of the sills. These represent gas bubbles frozen in the cooling magma. The original vesicles were filled later by minerals such as calcite and these can be seen in fresh rock in the quarries, but in surface exposures the mineral fills have been weathered out leaving the original vesicles.

Three linear clusters of dolerite dykes, arranged en-echelon within each cluster, and similar in composition to the sills, trend between north-east and east-north-east across Northumberland. The dykes are typically 3 to

10 metres wide and are considered to have been feeders to the sills. The northern set of dykes, the Holy Island Subswarm, lie to the north, between Ford and the Kyloe Hills. South of the Cheviot Hills, and emplaced along the Swindon and Cragend-Chartners faults, is the High Green Subswarm which can be traced for over 80 kilometres; one of the dykes has a width of up to 65 meters. And, farther south, the St Oswald's Chapel Subswarm can be traced from the Tyne valley, eastwards to the coast at Druridge Bay. One of this last set of dykes, the Haydon Bridge Dyke, is exposed in the north bank of the River Tyne at Wydon Nabb, near Haltwhistle.

Influence on the landscape

The Devonian lavas and granitic rocks form the massive rounded hills of the Cheviot massif, much of which lies above 300 meters, with the highest point on The Cheviot at 815 meters. The valleys are deep with steep-sided convex slopes. The rocks are not well exposed, except in the valley bottoms and on the tors, which characterise the hilltops on the granite, and where the volcanic rocks have been metamorphosed in contact with the granite. Craggs are few, though notable exceptions are Bizzle Craggs and Hen Hole to the north and west of The Cheviot respectively. In the eastern half of the massif, the drainage pattern that has developed on the igneous rocks is relatively simple and the density of streams is low. This contrasts markedly with that on the western side where the drainage pattern is intricate and dense. The wide, strikingly linear valley of the Harthope Burn has been carved along a major fault through the massif.

The lavas of the Cottonshope Volcanic Formation are marked by small, dark-coloured craggy outcrops which contrast with the surrounding outcrops of Dinantian sedimentary rocks. Small, long-abandoned quarries mark the outcrops. Because of their very small surface outcrop these rocks have only a modest effect of the district's landscape.

The Whin Sill-swarm is one of the best known features of Northumberland geology and is responsible for some of the county's finest, and most distinctive scenery. The north-facing cliffs, with the long, gentle southerly slopes, provided the Roman civil engineers with a natural defensive site for the construction of Hadrian's Wall. The massive, hard and resistant columnar-jointed dolerite imparts a distinctive character to these outcrops, which

contrasts strikingly with the generally lower ridges and crags (cuestas) formed by parallel outcrops of Carboniferous sandstone and limestone.

The Great Whin Sill was formerly worked on a large scale in quarries at Walltown and Cawfields. Landscaping of the former site has significantly lessened its visual impact as a man-made feature. In contrast, the profile of Cawfields Quarry stands as an obvious interruption to the line of Whin Sill crags. Both quarries offer opportunities to appreciate the nature of the Whin Sill and its role in creating the distinctive landscape of the Hadrian's Wall country. The crags at Steel Rigg and elsewhere are popular rock climbing localities.

East and north of Sewingshields the Whin Sill outcrops are locally concealed beneath spreads of superficial deposits. However, steep escarpments with bare crags of dolerite can be seen at Teppermoor Hill, around Gunnerton Nick and in the Swinburne, Thockrington, Sweethope, Bavington, Fontburn and Kyloe areas. Large working quarries at Keepershield, Barrasford, Swinburne,

Divethill, Howick and Longhoughton are conspicuous features in the local landscape, though their visual impact is subject to strict planning and environmental constraints. There are also abandoned quarries at Thockrington, West Whelpington, Ward's Hill and Ewesley.

Neither the Carboniferous, nor the Cainozoic dykes make any significant impact on the district's landscape; small long-abandoned quarries are still visible in the Acklington Dyke near Cartington.

Influence on biodiversity

The steep-sided valleys on the Cheviot volcanic rocks typically host grassland dominated by bent and fescue grasses or bracken, which alternates with areas of broken rock; much of this current pattern of vegetation results from modification by sheep grazing. The screes have sparse vegetation dominated by ferns including lemon-scented and parsley ferns. Soils derived from the volcanic rocks are usually base-rich and support some uncommon species such as maiden pink, Jacob's ladder, common rockrose and hairy rock cress. At higher levels

Crudely polygonal columnar jointing in Whin Sill, Sewingshields Crags



where slopes have lower angles, this gives way to a heather heath/acid grassland mosaic. On the flatter summits extensive areas of blanket bog have formed in the cool wet climate. Here species such as Sphagnum mosses, cottongrasses, cross-leaved heath and cloudberry are characteristic. Arctic alpine species and communities persist on The Cheviot, particularly on ungrazed ledges. Upland lichen species such as *Umbilicaria torrefacta*, *Melanelia hepaticolor* and *Sphaerophorus fragilis* occur on Cheviot itself, the Bizzle and Henhole have the richest flora and *Cladonia rangiferina* has been recorded from Braydon Crag.

Where free, or comparatively free, of superficial deposits, Whin Sill outcrops typically support rather thin, acid soils, which in places support a distinctive Whin Sill grassland flora including wild chives, biting stonecrop, rue-leaved saxifrage and mountain pansy.

Craggy outcrops, including those in abandoned quarries, offer important nesting sites for birds including kestrels, raven and peregrines, and possibly roosting sites for bats.

Economic use

The physical properties of the Whin Sill dolerite make it a good source of roadstone, crushed rock aggregate, rip-rap and armour stone. 'Northumberland Whinstone' has long been exploited for these purposes from quarries across the outcrop. Its intractable nature generally precludes its use as a building stone, though it has been employed locally in a few buildings, notably the now abandoned quarrymen's cottages at Barrasford Quarry. Large, abandoned quarries in the main sill at Walltown, Cawfields and West Whelpington were once important sources both of crushed rock for roadstone, and as shaped blocks or setts, for road paving and kerb stones. Similar dolerite was formerly worked from the Haydon Bridge Dyke, at West Mill Hills, east of Haydon Bridge: this quarry was backfilled and the site completely landscaped in the early 1980s. It was also formerly worked from one of the Carboniferous dykes north of Bellingham.

Very small pits have been worked for dolerite from the Cainozoic Acklington Dyke in the Cartington area, though there are no operating quarries within the present district.

'Whinstone' quarrying remains an important industry in Northumberland today, with quarries at Keepersfield,

Barrasford, Swinburne, Divethill, and, just outside the district, Howick and Longhoughton supplying crushed dolerite products for use widely across northern England.

On the south side of the Cheviot massif, the small intrusion of Devonian age near Biddleston has been worked for crushed rock and roadstone at Harden Quarry [NT 958 086]. The natural bright red colour of the rock makes it sought after for specialised uses such as surfacing the hard shoulders on Britain's motorways and, perhaps most famously, for lining The Mall in London.

The Cottonshope basalts have been quarried on a modest scale, probably mainly for local use as roadstone and walling stone. There is extensive use of local volcanic stone for walling despite its round profile.

Future working of any mineral deposit is dependent upon a complex range of commercial and planning considerations, but it seems likely that demand for roadstone, crushed rock and the other products currently extracted within the district will continue for the foreseeable future. Substantial reserves of rock of satisfactory quality are understood to remain at several, or all, of the working quarries within the district. Additional workable reserves of dolerite capable of meeting commercial specifications could no doubt be identified within the district, though planning and environmental conditions would have to be met in any proposals for working.

Conservation issues

The natural exposures of igneous rocks within the district are generally robust and none appears to be under threat.

Working quarries typically provide excellent representative sections of the geology, but by definition quarrying destroys the materials worked. However, the continually changing nature of the sections can yield invaluable insights into the rocks exposed. Accurate recording of such sections, accompanied by the collection and curation of representative specimens, can play a vital role in maintaining and furthering knowledge and understanding of the local geology.

By contrast, abandoned quarries are potentially at risk of becoming degraded or overgrown, either due to natural

deterioration or by inappropriate after-use and management. The planting of trees adjacent to the fine Whin Sill section at Walltown Quarry may be cited as an example of inappropriate management of a valuable and instructive geological site. The use of old quarries for landfill may threaten to damage or totally obliterate important sections, though none is known to be under any such immediate threat within the district.

The quarry faces at Cottonshope Head Quarry are now rather weathered, and in places degraded. Consideration might be given to restoring this section. The district also includes several abandoned quarries which, because of the significant geological features exposed, merit consideration for protection. Of particular note are the sections through the Whin Sill and adjacent country rocks at Ward's Hill Quarry. In addition to the range of geological features exposed here, the site has considerable historical significance for its place in the development of ideas on the nature and origin of the Whin Sill.

Exposures of the Acklington Dyke and adjoining wall-rocks at Cartington, though comparatively modest, offer a rare opportunity to examine this important, though otherwise poorly exposed, intrusion.

The Scroggs is an example of an SNCI listed for botanical interest that has geological links. This is an exceptional piece of grassland on the contact zone between the Whin Sill and limestones in the Tyne Limestone Formation. The pasture is among the richest found on any of the Whin Sill sites and its flora is outstanding with many species uncommon in north-east England.

Wider significance

The Cheviot volcanic rocks and Cheviot Granite are among the southernmost occurrences of a suite of igneous rocks of late Silurian to Devonian age, the members of which are distributed northwards to Orkney and Shetland. Volcanic rocks of this suite form such notable areas as the Ochil and Sidlaw Hills in the Midland Valley of Scotland, and the caldera-volcano at Glencoe in the Highlands. Though modern studies of the Cheviot rocks are few, these rocks contribute to our wider understanding of this important phase of igneous activity in the evolution of the British Isles.

The Whin Sill is generally regarded as the original sill of geological science and therefore has to be regarded as

one of the district's most important natural heritage features. It takes its name from the north of England quarryman's term 'whin', meaning a black, generally hard and intractable rock, and 'sill', meaning any more or less horizontal or flat-lying body of rock. Recognition of an intrusive igneous origin for the Whin Sill during the 19th century was based largely on studies within the present district, notably on sections exposed at Ward's Hill Quarry. Consequently, the term 'sill' became adopted by geological science for all near-horizontal and, within stratified sequences, broadly concordant, intrusive igneous bodies.

Since then, many studies of the Whin Sill-swarm and its associated dykes have drawn upon evidence gathered from its exposures in Northumberland and much of the large volume of earth science literature derived from these studies has significance well beyond the county. In addition to its geological importance, the striking geomorphological expression of the Whin Sill, and its exploitation by the Romans, has produced an internationally recognised landscape.

Geological SSSIs

Carboniferous and Permian Igneous rocks:

Cottonshope Head Quarry	[NT 803 058]
Steel Rigg to Sewingshields Crag	
	[NY 751 676 to NY 813 704]
Wydon	[NY 695 629]

Geological SNCIs

Allerhope Burn, Barrasford Quarry, Toddle, Reaver, Blindburn, Canker Cleugh, Carshope, Cawfield Crag, Divethill and Claywalls, Earlehill Quarry, Flodden Quarry, Fredden, Preston Yeaving Bell, Haltwhistle Burn, Harelaw etc. Burns, Horsdon Channel, Kyoel Hills, Raker Crag, Shiellow Crag, Shillhope Cleugh, Upper Breamish and Bloodybush Edge, Usway Burn, Walltown Quarry and Crag, Windyhaugh

Metamorphic rocks

Metamorphic rocks have formed through the alteration of other rocks by heat or pressure, or both. The original constituents of the rock may have been recrystallised to produce an assemblage of new minerals, textures and grain size. Metamorphism is the term applied to these processes. During mountain building, rocks buried deep within the Earth's crust may be affected by both intense heat and pressure, or by pressure alone, and hence undergo regional metamorphism. By contrast, when igneous rocks are emplaced the adjacent rocks are heated by the intrusion and experience thermal, or contact metamorphism; the zone of affected rocks surrounding an intrusion is known as a metamorphic aureole.

Metamorphic rocks in Great Britain

The most extensive outcrops of metamorphic rocks in Great Britain occur in the Scottish Highlands. Here a great variety of original rock types have been subjected to regional metamorphism of varying intensity during episodes of mountain building in the geological past, in some instances on several occasions. Elsewhere, for example in the Southern Uplands of Scotland, the Lake District and Central and North Wales, the lower Palaeozoic sedimentary and volcanic rocks also have undergone regional metamorphism, though at lower temperatures and pressures than those that affected rocks of the Scottish Highlands.

Contact metamorphic aureoles are associated with igneous intrusions of all ages throughout Great Britain. Those adjacent to large igneous bodies can be extensive, but the intensity of metamorphism declines with distance from the intrusion margin. Metamorphic aureoles adjoining smaller intrusions, including most sills, are typically narrow, and may be almost imperceptible adjacent to thin dykes. The approximate outer limits of the more extensive metamorphic aureoles are shown on some Geological Survey maps.

Metamorphic rocks in the district

Regional metamorphism has not affected any of the rocks of the region. In contrast, contact metamorphic rocks

occur adjacent to all of the intrusive igneous rocks present. Here, metamorphic aureoles are best developed adjacent to the Cheviot Granite Pluton and to the Whin Sills. The aureoles associated with the Devonian and Cainozoic dykes are typically narrow and the metamorphic effects limited.

Emplacement of the Cheviot Granite thermally metamorphosed the adjacent volcanic rocks and the effects are evident at outcrop for a distance of up to 2 kilometres from the contact. The most intense metamorphism is seen within 1 kilometre and is particularly well developed in eroded cappings of volcanic rocks that rest upon the granite well within its peripheral limit. Examples of these occur south-east of Langleeford, forming the tors of Long Crag, Housey Crag and Tathey Crag. Here the volcanic rock has been recrystallised into a 'sparkling' dark grey to black very finely granular hornfels, characterised by the growth of biotite, pyroxene and magnetite. The presence of the last mineral makes the hornfels more magnetic than the unaltered volcanic rocks.

Adjacent to the contacts of the Whin Sills, representatives of all of the district's sedimentary rocks display the effects of contact metamorphism. The degree of alteration is variable, though its intensity is greatest within a few metres of the igneous contact and within the rafts and fragments of sedimentary rock that have been engulfed by the intrusion. In many instances, alteration has been accompanied by the introduction of chemically active fluids associated with the intrusion, a process known as metasomatism. The metamorphic effects may be clear to the naked eye, for example where a rock is completely recrystallised, though in some rocks the alteration may only be detectable by microscopic examination. Examples are known where well-preserved fossils retain their original detail even though they are located within a few centimetres of the intrusion margin at Walltown Quarry and are also seen at Ward's Hill Quarry. Beautifully preserved spiriferid brachiopod shells occur in a fine-grained sandstone within a few centimetres of the lower contact of the sill.

The limestone has typically recrystallised to form white, saccharoidal limestone or marble. Good examples may be seen at several localities including Sewingshields Crag, Barrasford Quarry, Clay Walls and West Whelpington. A purple marble containing abundant disseminated crystals of fluorite, recently described from a raft of Oxford

Limestone at Barrasford Quarry, appears to be a unique example of fluorine metasomatism accompanying metamorphism; all exposures of this rock have since been removed by quarrying. Impure limestone and calcareous mudstone may be metamorphosed to form a calc-silicate rock characterised by an abundance of garnet, feldspar, vesuvianite, and chlorite. Fine examples of this rock, sometimes with clearly visible crystals of garnet and vesuvianite are common at Barrasford Quarry.

In mudstone, a 'spotting' effect is sometimes seen as the first signs of metamorphism as the contact is approached. The spots are small aggregates of minerals such as chlorite, cordierite and feldspar. Close to the contact, the mudstone is typically converted into a flinty-looking very fine-grained hornfels, which is sometimes referred to locally as 'whetstone'.

Coal may be converted into natural coke adjacent to dolerite intrusions. No surface exposures of this are known in the district today, though substantial amounts of coal were altered in this way, and rendered unworkable, adjacent to the late Carboniferous Haydon Bridge Dyke in the underground workings of Blenkinsopp Colliery.

Influence on the landscape

Several of the tors in the higher parts of the Cheviot massif are developed on contact metamorphosed volcanic rocks. In addition to those mentioned above, tors in hornfels are present to the west of the granite on The Schil [NT 870 223], West Hill [NT 894 213], Auchope Cairn [NT 892 198], and Hanging Stone [NT 892 190]; to the east are Middleton Crags [NT 977 215].

Because of their very limited extent, contact metamorphic rocks associated with the Whin Sills have a little or no impact upon landscape in the district.

Influence on biodiversity

Because of their very limited surface extent, contact metamorphic rocks within the district have very limited impact on biodiversity although some species may persist on ledges away from grazing animals. The metamorphic rocks in the Cheviots often have a rich lichen flora with good mosaics of crusts competing for space.

Economic use

None of the metamorphic rocks of the district have been specifically exploited. However, some of the harder

calc-silicate-rich rocks, formed by thermal metamorphism of the Oxford Limestone within the contact zone of the Whin Sill at Barrasford Quarry, are included within certain crushed whinstone products supplied by this quarry. Apart from such use it is extremely unlikely that any of the district's metamorphic rocks will ever attract commercial interest.

Conservation issues

Natural exposures of metamorphic rocks within the district are mainly closely associated with exposures of intrusive igneous rocks and, like them, may be assumed to be generally robust. Comments made on the conservation of intrusive igneous rocks in working quarries (p. 52), applies equally to metamorphic rocks.

Wider significance

Despite the great importance of the Whin Sills in the development of understanding of such rocks, as evidenced by the voluminous technical literature on their form, composition, age and mode of origin, little attention has been directed towards the metamorphic effects associated with them. Thus, although of limited extent, the metamorphic rocks associated with the Whin Sills, in particular, offer considerable potential for future research on metamorphic processes in such geological environments.

Although the volume of metamorphic rocks within the district is small, they are extremely important in giving clues to the district's geological evolution.

Major tor in andesite at Housey Crags © Simon Fraser



Quaternary deposits and landforms

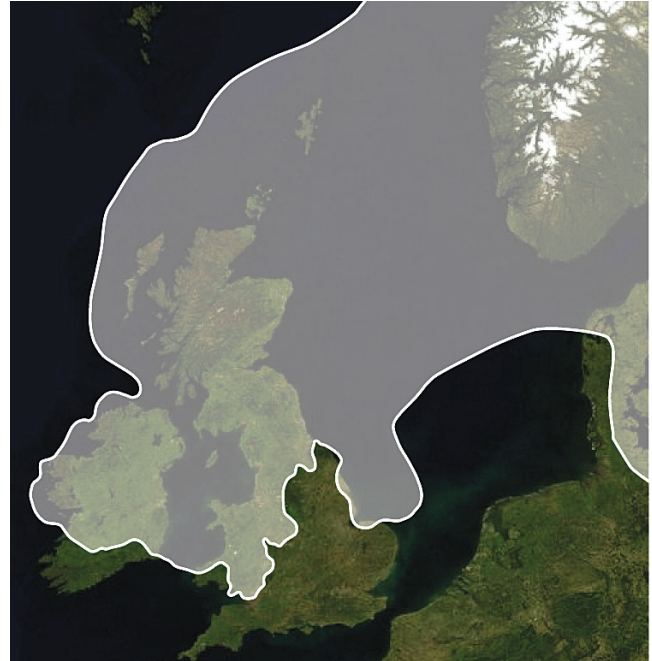
The Quaternary Period spans the last 2 million years, a time dominated by a succession of 'ice ages'. The process of glaciation, the scouring of uplands by flowing ice, and the subsequent transport of material by ice and meltwater flow into lowland and offshore areas, produced distinctive sediments and landforms. During the Holocene Epoch (the last 11 000 years), following the decline of the ice, the landscape has been dominated by less dramatic processes. Holocene sediments in Britain include peat and alluvium, both of which give vital information regarding the climate and environment since deglaciation.

The study of Quaternary deposits and landforms enables links to be made between the behaviour of ice-sheet systems across continental-scale areas, and the mechanisms and processes of climatic and oceanic change.

Quaternary deposits and landforms in Great Britain

The landscape of Britain is dominated by Quaternary deposits and landforms. Throughout the last two million years successive glaciations have advanced across the landscape, sourced from the upland areas of Scotland, Wales, northern England and Scandinavia. Early in the Quaternary, ice advanced as far south as the Thames valley, with ice possibly even streaming past the Scilly Isles. Unfortunately, the nature of glaciations is that their imprint on the landscape is largely destroyed by any subsequent glacial advance, so most evidence for glacial activity in Britain dates from the most recent cold period, the late Devensian Glaciation, which spanned the period between about 25 000 and 11 000 BP (Before Present). The late Devensian ice was less extensive than earlier glaciations, though its southern limit formed a margin running between The Wash and the Bristol Channel, and in the west ice reached the edge of the continental shelf.

Glacial deposits and glaciated landscapes in Britain are highly variable. The processes that created them are complex, and operated over differing timescales; some were active throughout the period, whilst others switched on and off depending on ice dynamics, climate or factors such as sediment supply. However, as a



Limits of the late Devensian Glaciation of Britain (after Boulton, 1977 and Carr et al., 2006)

general rule areas dominated by glacial erosion are to be found in upland regions, such as the Highlands of Scotland and the Lake District. These are characterised by high mountains, steep slopes, and smoothed bedrock surfaces. The valleys separating peaks tend to be 'U-shaped' and within these valleys some deposits can be found relating to the final departure of the ice. Moraine ridges mark positions of glacier retreat, and small areas of sand and gravel outwash indicate where meltwater transported the last of the glacier sediment load onto flatter ground. Lowland areas are dominated by depositional processes. Here tills ('boulder clays') form thick blankets over extensive areas. In regions that were near the margins of retreating or still-standing ice masses, glaciofluvial material, such as widespread sheets of sand and gravel, is commonplace. Tills and glaciofluvial material are often sculpted by the iceflow to produce landforms such as drumlins (elongate mounds) that give indications of ice-sheet behaviour.

At the Last Glacial Maximum (LGM— possibly between 35 000 and 22 000 BP), much of Britain was completely covered by an ice-sheet, in places over 1 kilometre thick and travelling at between 1 and 1.5 kilometres per year.

This ice acted both as a massive bulldozer and also a huge conveyor belt, simultaneously grinding and shaping the landscape and sediment beneath the ice, and transporting vast volumes of debris created by this erosion to lowland, coastal and offshore areas. The great till plains of Cheshire and Lancashire show how the ice moved out from mountain areas, streamlining the soft sediment beneath it into drumlinoid forms. Beyond the margins of the ice-sheet, huge volumes of meltwater transported many varied grades of material across the lowlands. The flatlands of East Anglia are a testament to the massive meltwater discharges produced by the ice, which were able to carry sand, gravel and cobbles huge distances.

Ice streams are the most dynamic component of modern ice-sheets such as those seen in Greenland and Antarctica, and therefore are important in driving ice-sheet evolution. Studies in Antarctica, for example, have shown that ice streams account for more than 90 per cent of mass transfer within the ice-sheet and leave behind characteristic landscapes when they retreat.

However, some 'continental' glacial locations, such as parts of modern day Antarctica, Svalbard and high-Arctic Greenland that endure relatively arid and cold conditions distant from a source of snow precipitation, experience cold-based glacial ice. Although the mechanisms are the subject of some debate, it is acknowledged that warm-based glaciers and ice-sheets are faster flowing, more erosive and more dynamic, than cold-based systems. Cold-based glaciers are often frozen to their bed, largely unable to perform appreciable amounts of erosion, and as a consequence are slower-flowing, producing smaller amounts of till and meltwater. Essentially cold-based ice can 'protect' a landscape from erosion throughout a glacial episode.

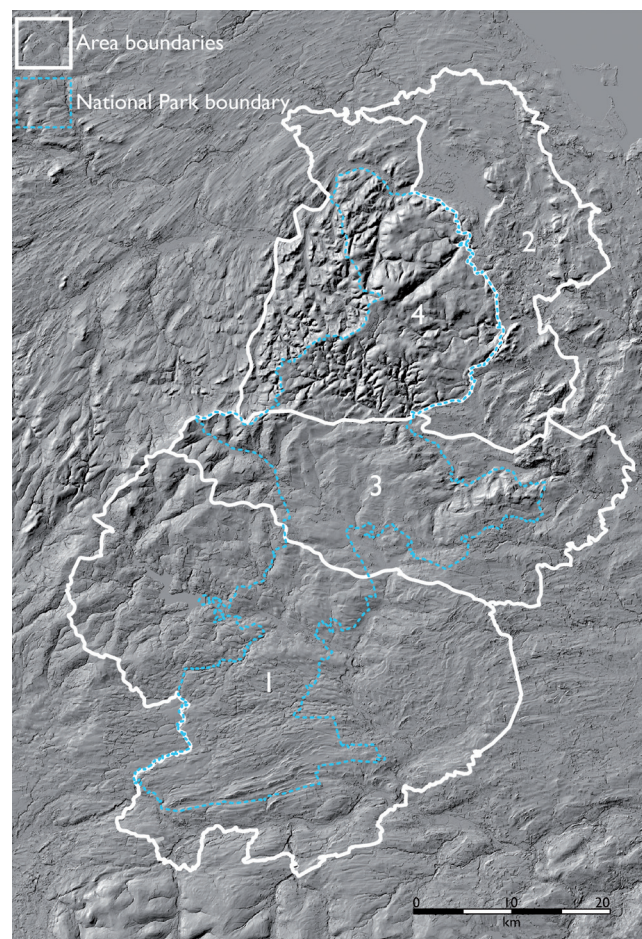
In Britain during the last glaciation, eastern upland areas such as the Cairngorm massif and Cheviot massif experienced cold-based glacial ice. Further west, warm based ice can be seen to have carved the spectacular troughs and steep mountains of the Lake District, Snowdonia and Western Scottish Highlands.

Quaternary deposits and landforms in the district

Throughout much of the Devensian glaciation large areas of Northumberland lay beneath fast-moving, dynamic parts of the British ice-sheet. The effects of warm-based ice streams can be seen in the landscape surrounding the Cheviot massif, in the Tweed Basin and Tyne Gap, where they have effectively moulded and streamlined the land.

However, the Cheviot massif appears to have deflected much of the streaming ice around it to the north and south, remaining relatively unaltered. In the lee of the massif lay an area of slower-moving ice, and during deglaciation this difference in velocity had a significant influence on the resulting landscape character. In order to simplify description the district has been divided into four areas, illustrated below.

Locations of areas described in this section (Hillshade image derived from NEXTMap® © Intermap Technologies Inc.)



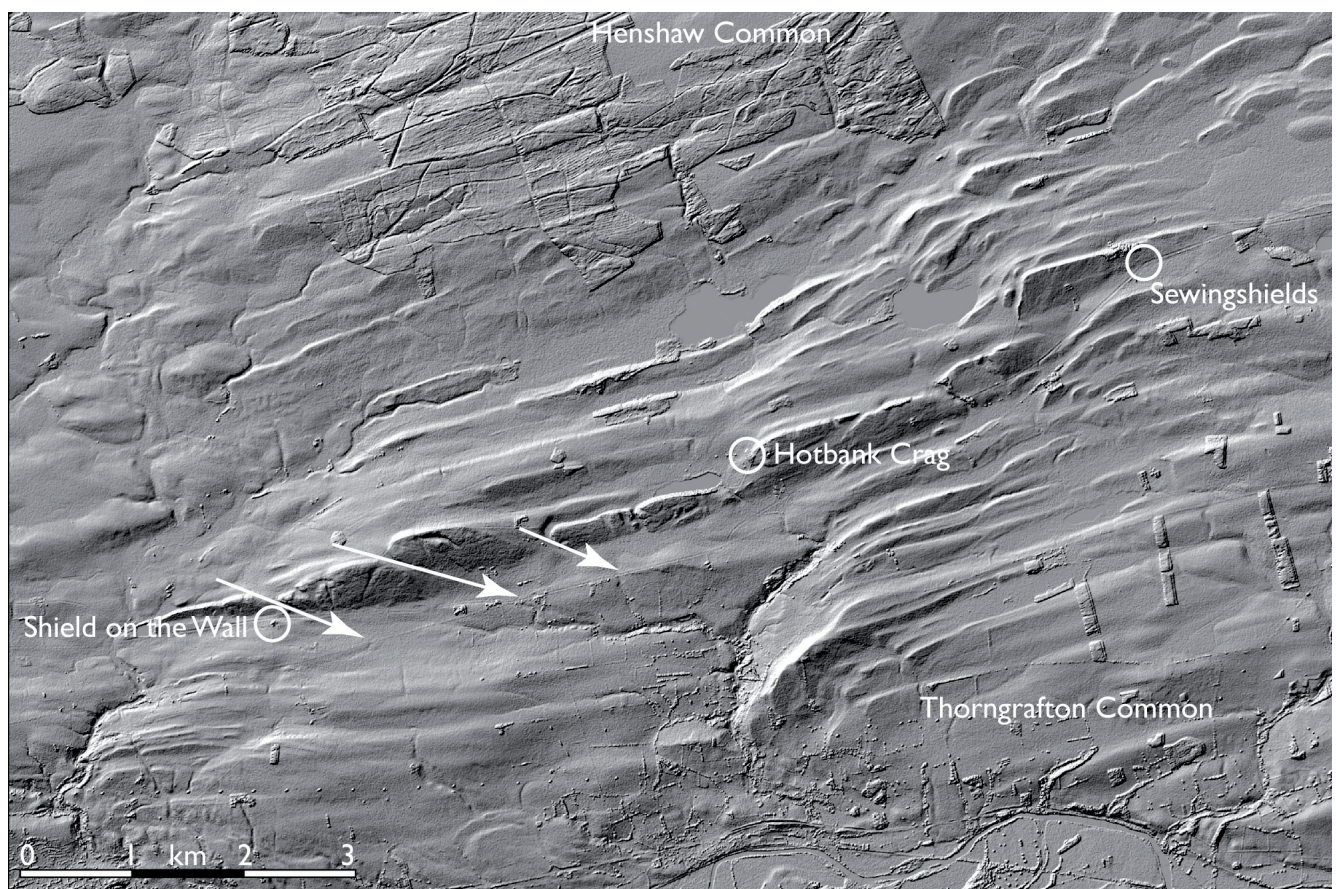
Area I – Hadrian’s Wall country, the North Tyne and Redesdale

Bedrock streamlining

The landforms here are dominated by the underlying bedrock. The differential weathering of Carboniferous rocks has produced a cuesta landscape of strong east-west trending ridges, with the dolerite of the Great Whin Sill, on which the Wall is built, forming the largest of these ridges. With this bedrock dominance over the landscape one might not expect evidence of Quaternary glaciation to be significant in the region. However, the form of the Whin Sill and dipping ridges of bedrock strata to its north and south has been accentuated by the action of subglacial erosion and shows obvious streamlining, caused by ice flowing from west to east across Northumberland parallel to the strike of the bedrock. In places, glacial loughs (lakes) have been scoured out in softer ground between harder bedrock strata. The Whin Sill itself shows remarkable

topography from the air (p. 22). The section between Shield-on-the-Wall and Sewingshields exhibits classic ‘crag and tail’ topography, with ice smoothed stoss sides (up-ice crag tops), and lineated and streamlined lee side (down-ice) features. Hotbank Crag is a particularly fine example. This section of the sill is further cut at an oblique angle from west-north-west to east-south-east, by a series of subglacial meltwater channels, excellent examples being those at Steel Rigg and Shield-on-the-Wall. Western edges of crags are smoothed, and ‘tail’ features show limited development eastward in their lee. This pattern exists as far north as Henshaw Common and as far south as Thorngrifton. Nowhere else in the district is this bedrock streamlining more apparent. To the east, in the area around the Hallington reservoirs, the strike of the bedrock strata turns north-south and much of the streamlining pattern is lost. Virtually no streamlining can be seen in the bedrock forms from here until the north of the district, between Sweethope Crags and Kirkwhelpington.

The streamlined bedrock of the Whin Sill (arrows indicate location of subglacial meltwater channels)
(Hillshade image derived from NEXTMap® © Intermap Technologies Inc.)





Sycamore Gap: a possible subglacial meltwater channel, cutting through the Whin Sill © Graeme Peacock www.graeme-peacock.com

Superficial streamlining

Between the dipping Carboniferous strata, glacial action has left another legacy. The lower reaches of each dip slope are filled with glacial till, which has been smeared across the landscape by the streaming ice. To the north of the Wall country around Henshaw, Haughton and Thirlwall commons, till thicknesses increase to such an extent that the bedrock strata are now buried fairly deeply, although their expression may still be reflected in the overlying till topography. Ice streaming in this region has led to drumlinisation of the till, creating a near-mirror of the streamlined bedrock seen further south, though formed of different material. These drumlinoid features are elongate mounds of glacial material up to 3 kilometres long, though most are between 800 and 1500 metres in length. They appear to be rock cored, with Carboniferous rocks forming their spines, and are composed of massive, clay-rich till. The till here contains 'erratics', large boulders transported by the ice, some of which have sources as distant as Criffell in Dumfriesshire, Shap and Eycott Hill near Penrith.

To the south of the Tyne valley, east and west of the Allen gorge, more of these drumlinoid forms can be seen,

although here they overlie more gently dipping bedrock, and therefore have less surface relief than those immediately to the north of the Whin Sill. In the region where the sill turns to the north, around the Hallington reservoirs, and to the south of Kirkwhelpington some impressive elongated but low relief drumlinoid forms occur, aligned south-west–north-east.

Glaciofluvial deposits

Deposits resulting from glacial meltwater are mainly to be found in the Tyne valley around Haltwhistle and Hexham, and to the west of Chollerton. These deposits form hummocky topography; a result of their mode of deposition at the margin of a wasting ice mass and from incision by meltwater and alluvial streams close to the ice. Oscillating retreating ice margins repeatedly bulldozed and redistributed sediment, whilst all the time more sediment was being supplied by meltwater.

After the ice had disappeared from the area, reworking processes continued to operate. In modern proglacial (in front of the ice) environments, such as parts of Iceland, it is common to find areas of disordered terrain beyond the snouts of retreating glaciers. These areas often

contain large buried blocks of ice, sometimes tens of metres in thickness, and hundreds of metres in lateral extent. As these masses slowly melt, a process of topographical inversion takes place whereby higher hummocks that were once ice-cored melt away to leave hollows, sometimes known as 'kettle holes', whilst the low areas previously at the sides of the buried ice become filled with debris and form hummocks.

Glaciofluvial deposits are normally composed of sands and gravels, and often contain pebble and cobble beds. Quite often these deposits are bedded as a result of deposition by dispersed meltwater flow. They have a coarse fabric and tend to be free draining.

Fan deposits

A significant fan has accumulated at the mouth of the Allen gorge into the Tyne valley. This is a postglacial deposit that is likely to have formed early in the Holocene Epoch, and may reflect reactivation of the Stublick Fault following unloading by retreat of the ice-sheet. The fan is largely composed of pebble- and cobble-grade debris, and topographically forms a sequence of at least five overprinting fans. The current level of the River Allen is at least 50 metres below the level of the topmost fan surface, reflecting increased incision, or trenching, since formation, and a reduction in debris supply throughout Holocene time.

Peat

Peat is made up of partially decomposed vegetation that has accumulated in waterlogged conditions throughout the Holocene. Its formation was stimulated by increased rainfall and human forest clearance. Blanket mire is peat more than 0.5 metres deep that forms over large areas in hollows and over undulating flattish land. Raised mires form through succession and terrestrialisation from lakes or pools. Peatland habitats are found widely throughout the southern section of the district particularly between the dipping Carboniferous strata, the most important being the Border Mires; a collection of internationally important deep peat sites (up to 12 metres) on the Northumberland-Cumbria border. These peat deposits have been substantially modified by afforestation, drainage, peat extraction, overgrazing and burning.

Alluvial deposits

Alluvium, material resulting from fluvial deposition, is widespread on the floors of the Tyne and North Tyne

valleys. These valleys almost certainly represent preglacial drainage pathways, which have inevitably been modified by iceflow. The South Tyne, in places up to 1.5 kilometres wide, is floored with successive deposits of alluvial clay, silt and sand, often overlying glaciofluvial gravel. Sequences of abandoned alluvial terraces are very distinctive in the Haltwhistle region, and most terraces in the Tyne catchment are predominantly composed of coarser sands and gravels, frequently overlying till deposits. This overall coarsening upwards of units through the alluvial and terrace sequence, reflects both the age and changing character of the Tyne valley landscape. The highest terraces are oldest, and were deposited early in the Holocene, or even during the final stages of the late glacial period (about 15 000 years ago). Debris supplies in the area were far greater then due to the recent retreat of the ice than they are at present, and likewise the amount of fluvial discharge was probably greater and more responsive to climate, due to the combination of melting ice and a lack of vegetation to slow river response. Later terraces were deposited during periods where the available debris in the catchment was diminishing and vegetation was more established. Both these factors regulated river response, and reduced the Tyne River system's ability to carry large bedload clasts.

Area 2 – North and east of the Cheviot massif

Bedrock streamlining

Streamlined landscapes can be seen on the northern flanks of the Cheviot massif, and further to the north in the Tweed Basin. The northern flanks of the massif, around Kirk Yetholm and to the north of the Glen valley, between Westnewton and Branxton, show clear alteration of drainage pathways and valley-side slopes by ice moving from south-west to north-east. Venchen, Staerough, Pawston and Moneylaws hills are all good examples of streamlined masses. Many of these streamlined summits display distinct 'tail' features in their lee to the north-east. Between these hills drainage is now concentrated in sub-parallel networks, oriented south-west-north-east, draining to the north-east. It is assumed that prior to glaciation drainage networks would have resembled more typical dendritic patterns, such as those found in the vicinity of the Capehope and Heatherhope burns. Valley side slopes in this area tend to be more linear in comparison to the more convex profiles of valleys to the south.

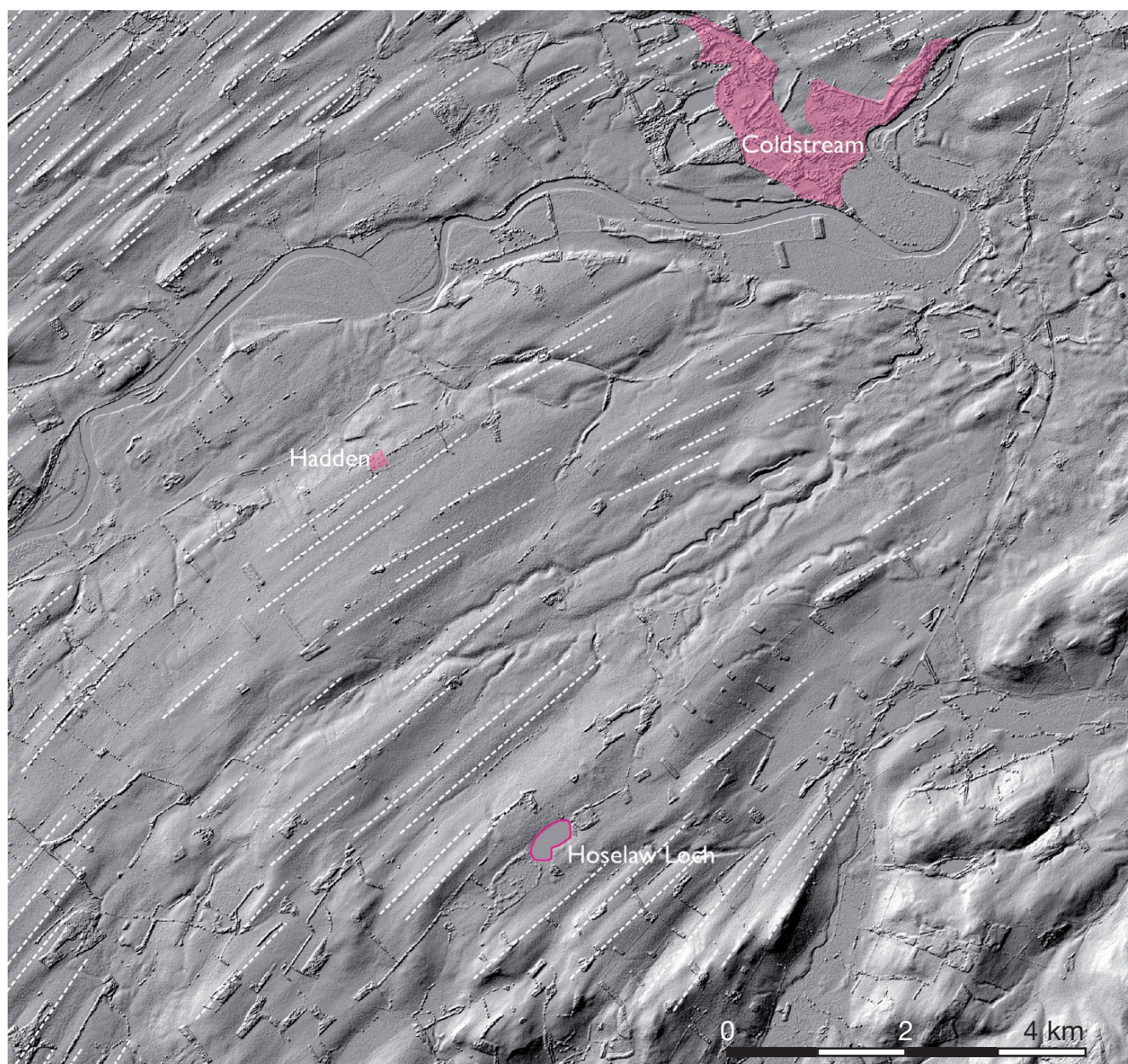
Streamlining in superficial deposits

To the north of The Cheviot in the region between Hoselaw Loch, Hadden and Coldstream, the landscape is dominated by highly-elongated, relatively low-lying mounds composed of glacial till and glaciofluvial deposits.

This distinctive topography was produced by the action of the Tweed Ice Stream flowing over a deformable bed

of glacially-derived material. The majority of these landforms can be classified as drumlins, megadrumlins and megaflutes and their long axes are indicative of ice-sheet flow direction. Furthermore, their degree of elongation is thought to reflect the relative velocity of ice flow. The sub-parallel landforms in this part of the Tweed valley indicate general north-eastward and eastward ice flow, towards the present North Sea coast.

Streamlined topography around Coldstream. Modification of the landscape due to high velocity ice at the base of the Tweed Ice Stream. Dashed lines indicate crests of mega-scale glacial lineations (Hillshade image derived from NEXMap® © Intermap Technologies Inc.)



Glaciofluvial deposits

The area to the east of The Cheviot is dominated by glaciofluvial deposits. In general these have been deposited by glacial meltwater, both proglacial and subglacial. There is evidence for prolonged retreat of the major mass of the ice-sheet, with interruptions as the ice halted its retreat and maintained stable positions across this part of the landscape.

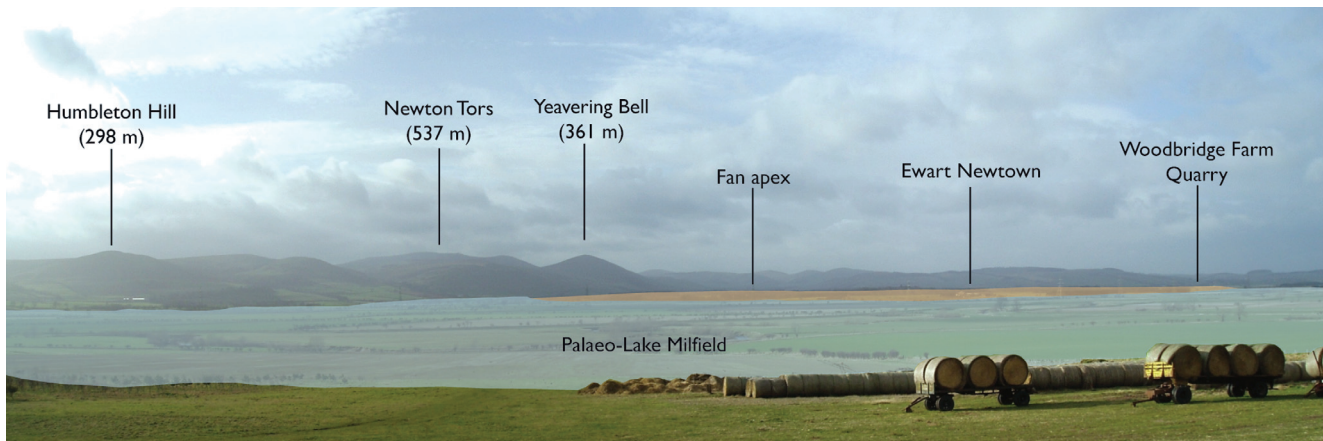
The area of the Till valley between Wooler and Powburn displays extensive areas of mounds and hummocks, dissected by channels, predominantly formed by the action of meltwater from the retreating ice-sheet. The mounds are mainly composed of sands and gravels, in places the sands are bedded implying deposition in lakes

as ponding of water occurred at the margins of the ice-sheet, however the sand beds are frequently interrupted throughout the vertical sequence by gravels.

These gravel units have erosional lower surfaces and, in section, display channel forms showing that they were most likely deposited by a fast flowing stream or river. The repetition of the sand-gravel-sand sequence up through the stratigraphy indicates that this was a highly dynamic and variable environment. As the major mass of the ice-sheet retreated towards the north, stagnant ice and meltwater formed the landscape at the margins of the ice. The large debris supply, coupled with the availability of large amounts of meltwater enabled this somewhat chaotic and distinctive topography to develop.

Section at Roddam showing medium (fine dashed line) and coarser (thick dashed line) bedded sands punctuated with channel system activation (gravels)





View from south of Doddington, looking west. Simplified reconstruction of palaeo-Lake Milfield, showing probable lake extent (blue) and location of fan (brown)

Lake deposits

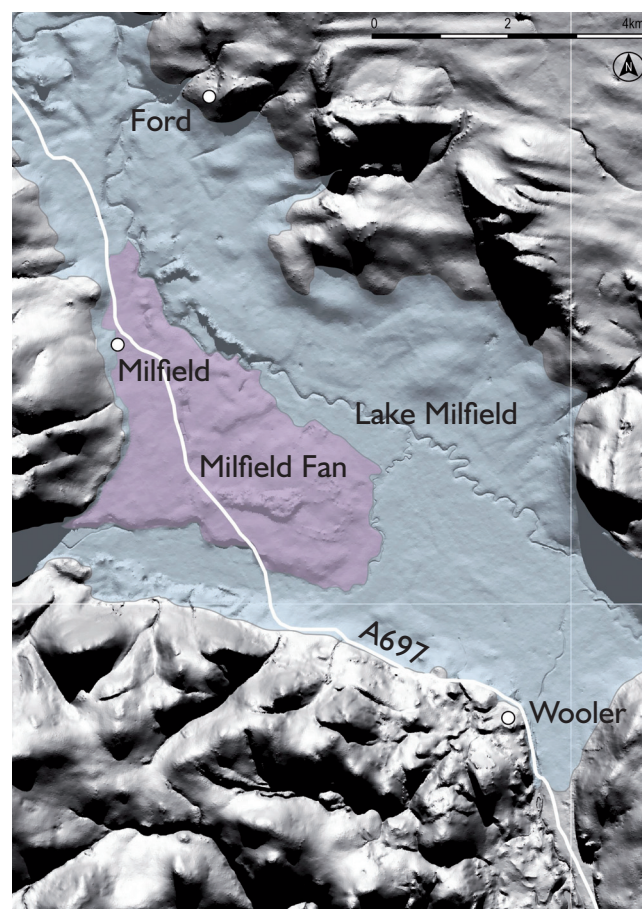
East of The Cheviot, there are two areas of ancient lake deposits, both of which are currently being exploited for building resources. The Milfield Plain stretches some 11 kilometres from Ford in the northwest to the south of Wooley, and is 3 kilometres wide at its broadest point between Bendor and Doddington. The plain has been interpreted as an ice-dammed lake due to its location at the margin of the retreating Tweed Basin portion of the British ice-sheet toward the end of the main late Devensian Glaciation. There are no exposures of the lake deposits themselves on the Milfield Plain. However, borehole records show that beneath the topsoil of the plain lie significant thicknesses of soft red clays, interspersed with lenses of fine to medium sands. These sedimentary assemblages support the interpretation of the area as an ice-marginal lake bed. The plain is older than Holocene in age, as it is overlain by a low fan emanating from the Glen valley, itself demonstrably at least 15 000 years old (see below).

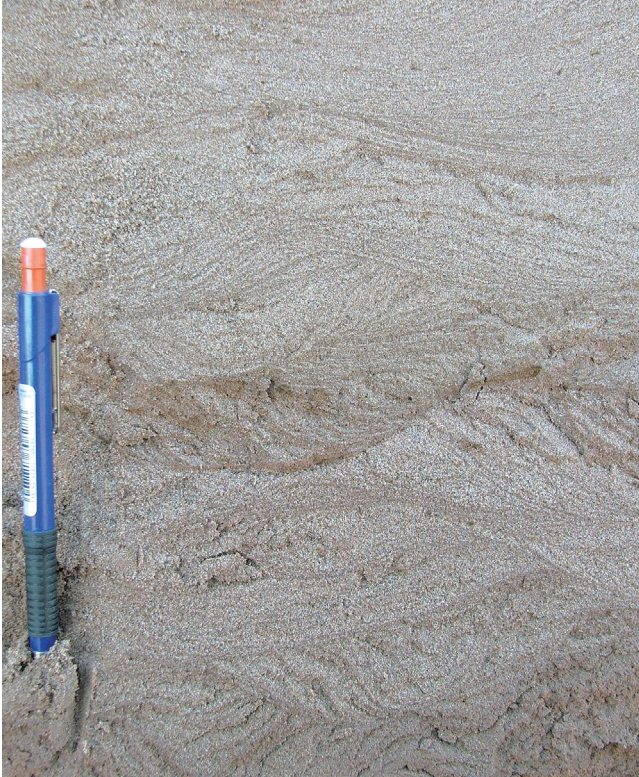
Further to the south at Thrunton, the brick clay quarry sits upon a deposit of at least 10 metres of interbedded brown and grey clays; these are likely to have been formed by ponding of meltwater between the retreating ice and surrounding hills.

Fan deposits

Issuing from the Glen valley is a low-angled fan whose toe stretches from Milfield Hill to Akeld Steads. The apex of the fan is sited around Lanton. Holocene fluvial activity of the River Glen has removed a considerable portion of

Reconstruction of palaeo-Lake Milfield, with area of extant glaciofluvial fan at Milfield. Fan apex is at 55 metres OD, therefore the lake shoreline has been drawn at 60 metres. Water levels will have fluctuated throughout the life of the lake (Hillshade image derived from NEXTMap® © Intermap Technologies Inc.)





Ripple cross-bedded sands in section at Woodbridge Farm Quarry



Ice-wedge cast in section at Woodbridge Farm Quarry. Ice wedges form under intensely cold conditions, as water freezes in vertical cracks in soils, and repeated freeze-thaw cycles widen the crack, into which larger debris is sorted by the freezing and thawing, causing swelling and shrinking of the soil

the fan, and dissected through its southern boundary with the lower slopes of Yeavering Bell and Akeld Hill. The fan itself is composed of bedded sands and gravels, with some intricately cross-bedded units, indicating periods of steady flow, punctuated by periods of fluctuating flow. Deposition probably took place in a lake over a relatively long period. The fan's low-angled upper surface and composition dominated by finer grain sizes indicate that a large degree of the sorting of material had already taken place further upstream. Consequently, the toe area of the fan is dominated by finer grain sizes: medium-grained gravels to medium-grained sands.

The timing of fan formation is relatively clear. As deposition took place in a lake environment, fan construction almost certainly took place during deglaciation between 18 000 and 15 000 years ago, when the British ice-sheet flowing from the Tweed Basin and down the North Sea ponded meltwater against the

flanks of the Cheviot massif. Further support for this period is found in the upper surface of the fan itself, where large scale periglacial frost-wedge casts can be found. These are unlikely to have formed during fan construction, as they do not form underwater. However, the onset of a glacial event known as the Loch Lomond Stadial, at around 12 000 BP, saw a return to full glacial conditions across the North Atlantic Margin for a millennium, and saw the regrowth of glaciers in Scotland, Wales and the Lake District. While there was unlikely to have been regrowth of ice in the Cheviot massif, it was most certainly affected by periglacial activity.

Alluvial deposits

Alluvium is widespread on the floors of the Till, Glen and Ingram valleys. In almost all places these three major rivers have dissected glaciofluvial deposits, both removing and reworking the material, and creating flat floodplains and terraces. The floodplain of the River Till

across the Milfield Plain is extensive, however the action of the River Till system has not created this landscape, it has merely exploited a pre-existing flat surface; lakebed deposits of palaeo-Lake Milfield, over which it has been able to meander and flood.

Sequences of abandoned alluvial terraces are very distinctive in the Brandon region, and most terraces in this part of the upper Breamish catchment are predominantly composed of coarser sands, gravels and cobbles. These terraces are likely to have been deposited early in the Holocene Epoch, or even during the final stages of the late glacial period (about 15 000 BP), when sediment supplies were far greater than at present due to the recent retreat of the ice. Moreover, the amount of fluvial discharge was probably greater and more responsive to climate, due to the combination of melting ice in the vicinity, and a lack of vegetation cover to slow river response times.

Cobble gravels in section of River Breamish at Branton. Imbrication, or stacking of the clasts is clear, as is the less coarse alluvial deposit in the upper part of the section, relating to lower energy flow regimes. These most likely occurred long after the coarse material was deposited by glacial meltwater flow. Subsequent late Holocene activity has seen downcutting through the older deposits



It is unlikely that modern flow regimes in the upper Breamish valley are able to transport significant quantities of the larger grade bedload clasts that are evident. Winter storms and snow-melt events are the primary agents of remobilisation of this material, which was deposited under early Holocene or lateglacial flow regimes.

Area 3 – Lower and Upper Coquetdale

Bedrock alteration

In aerial view the overall character of the bedrock exposure in this area is very different to that found in most other parts of the Cheviots and surroundings. The eastern part of the area is dominated by outcrops of the Fell Sandstone, however the western fringes of Coquetdale are bounded to the north by bedrock that appears to have undergone significant *in situ* weathering (saprolite). Slopes here are commonly deeply incised by a higher density of drainage networks than found to the north and east of the Cheviot massif. No exposures of weathered material have been found to date, however the landscape exhibits similar characteristics to areas where known saprolitic rocks occur in the north of the Cheviot massif, where several metres of rotted material are to be found at surface (see Area 4).

In the area that forms a triangle between Alwinton, Thropton and Whittingham the landscape has undergone streamlining by ice, and bedrock exposures illustrate the effects of ice moving from west-south-west to east-north-east. Streamlining of the Simonside Hills and the Fell Sandstone hills to the north of Rothbury is less obvious, though the overall plan-form of the outcrops show that the area has been overridden by ice.

Superficial streamlining

Thin till is present in the area to the north-west of Rothbury, though its distribution is patchy, with large areas of streamlined bedrock to be found close to, or at surface. The effects of ice movement are less obvious in the Coquetdale area than to the south, as its proximity to the Cheviot massif ensured that iceflow was slower here. The Tyne Gap Ice Stream flowing south-eastwards from the Kielder Forest area would have encountered both a topographical high, and also possibly a small independent ice centre within the British ice-sheet centred on The Cheviot. This would have had the effect of deflecting iceflow to the south, and causing it to slow at the northern fringes of the stream.



Panoramic view from near Glanton Pyke, looking southwards toward Whittingham. The ridges marked 'a' and 'b', are clearly visible on the valley floor and were probably formed by glaciofluvial outwash processes

Glaciofluvial deposits

There are few areas of obvious glaciofluvial deposits in the Coquetdale area. One significant example is to be found in the valley of the River Aln, west of Whittingham, where a series of flat-topped ridges run sub-parallel to the main axis of the valley floor. Previous geological surveys have identified these ridges as being composed of sand and gravel, although they have not ascribed a mechanism to their formation. Though no exposure has been found thus far, it is likely that these features are associated with glaciofluvial outwash processes at, or beyond, the margin of a retreating glacier.

Alluvial deposits

There are extensive areas of modern and ancient alluvial deposits in the Coquetdale area. For most of its length, Coquetdale itself displays a wide floodplain, from its upper reaches at Alwinton down to Rothbury where the floodplain narrows through the gap in the Rothbury Forest hills. East of Rothbury the floodplain, although narrower, displays some well-developed terraces in the region to the south of Longframlington. The width of the

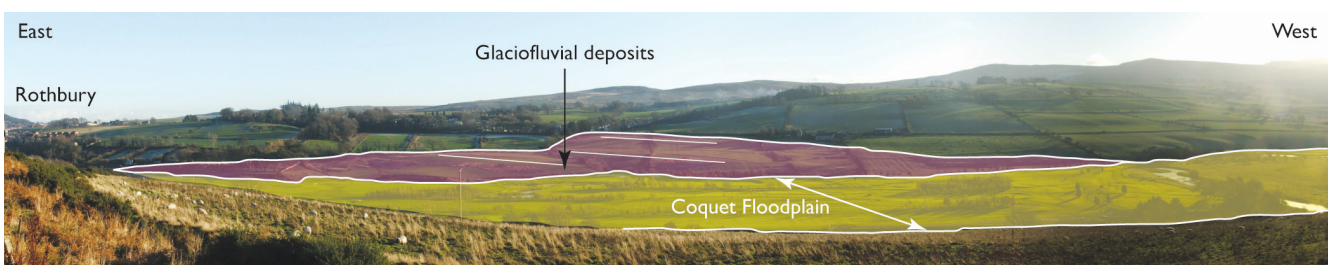
floodplain upstream from Rothbury is testament to the size of the drainage basin of the Coquet. Its large catchment, coupled with suitable bedrock lithologies and climate, ensure that river load is generally high.

The floodplain development is likely to have been constant throughout the Holocene and alluvium was deposited on top of remnants of glaciofluvial activity from the end of the Devensian glaciation, some of which can be seen to the south of the golf course at Rothbury.

Peat

Blanket mire has formed on flat and undulating ground in these areas, for example the tops of the Fell Sandstone ridges at Simonside and Harbottle. In larger depressions raised mires have formed, the most significant being the Otterburn Mires SSSI sites located across the Otterburn Training Area and sites such as Boddle Moss and Caudhole Moss within the Simonside Hills SSSI. Historically, some of these sites have been modified by drainage, overgrazing and burning.

View from Pondicherry near Rothbury, looking southwards over the Coquet floodplain. Recent Holocene fluvial activity has ensured the floodplain has remained active. Low relief, linear ridges of glaciofluvial deposits are visible on the southern side of Coquetdale



Area 4 – The Cheviot massif

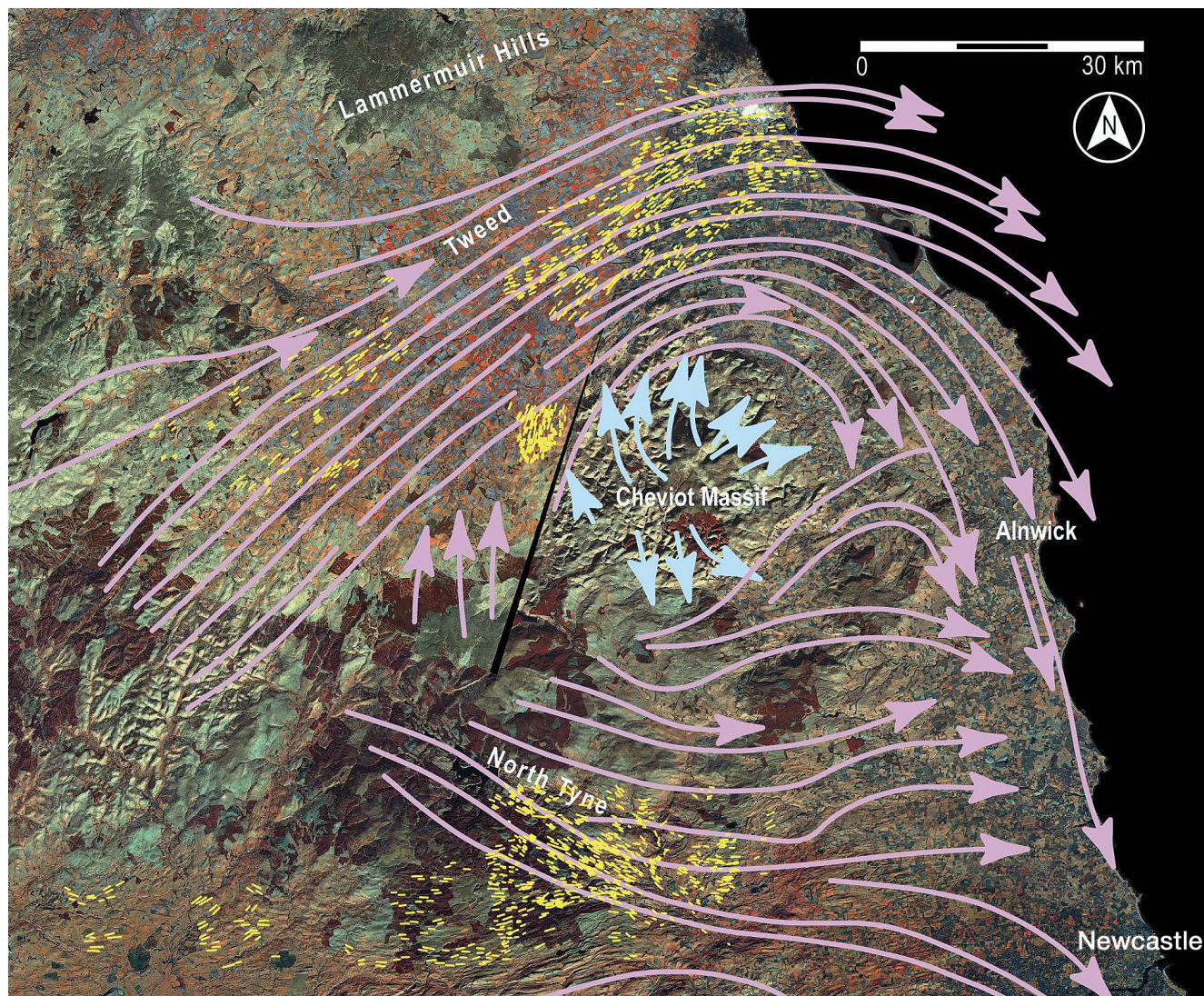
The Cheviots do not display the characteristic features that are usually associated with Britain's glaciated upland areas (p. 56). The reasons for this are several, and are intrinsically linked with the position of the massif in relation to the British ice-sheet and major ice source areas in the rest of northern Britain and Scandinavia.

The Cheviot massif apparently deflected much of the streaming ice around it to the north and south, remaining relatively unaltered. The massif itself is likely to have supported an ice cap of its own which, during glacial maximum conditions, may well have operated as part of

the larger British ice-sheet, however later in the glacial period, as the British ice-sheet thinned, the Cheviot Ice Cap is likely to have maintained its own flow regime.

The massif lies relatively distant from the source of most snow precipitation, which fell predominantly over the uplands in the west of the British Isles. It is also well to the east of the proposed ice divide (i.e. the 'ice-shed' running roughly north-south, dividing eastward flowing ice, from that flowing to the west). As a result it is likely that The Cheviot endured relatively arid and cold conditions throughout glacial periods, being far removed from any maritime influence, and lying in the

Proposed flow regime in the Cheviot region (after Clapperton, 1971), with cold- and warm-based ice shown by blue/pink colouration of arrowed flowlines. Position of mega-scale glacial lineations shown in yellow (Clark et al., 2005). After Everest et al., 2006



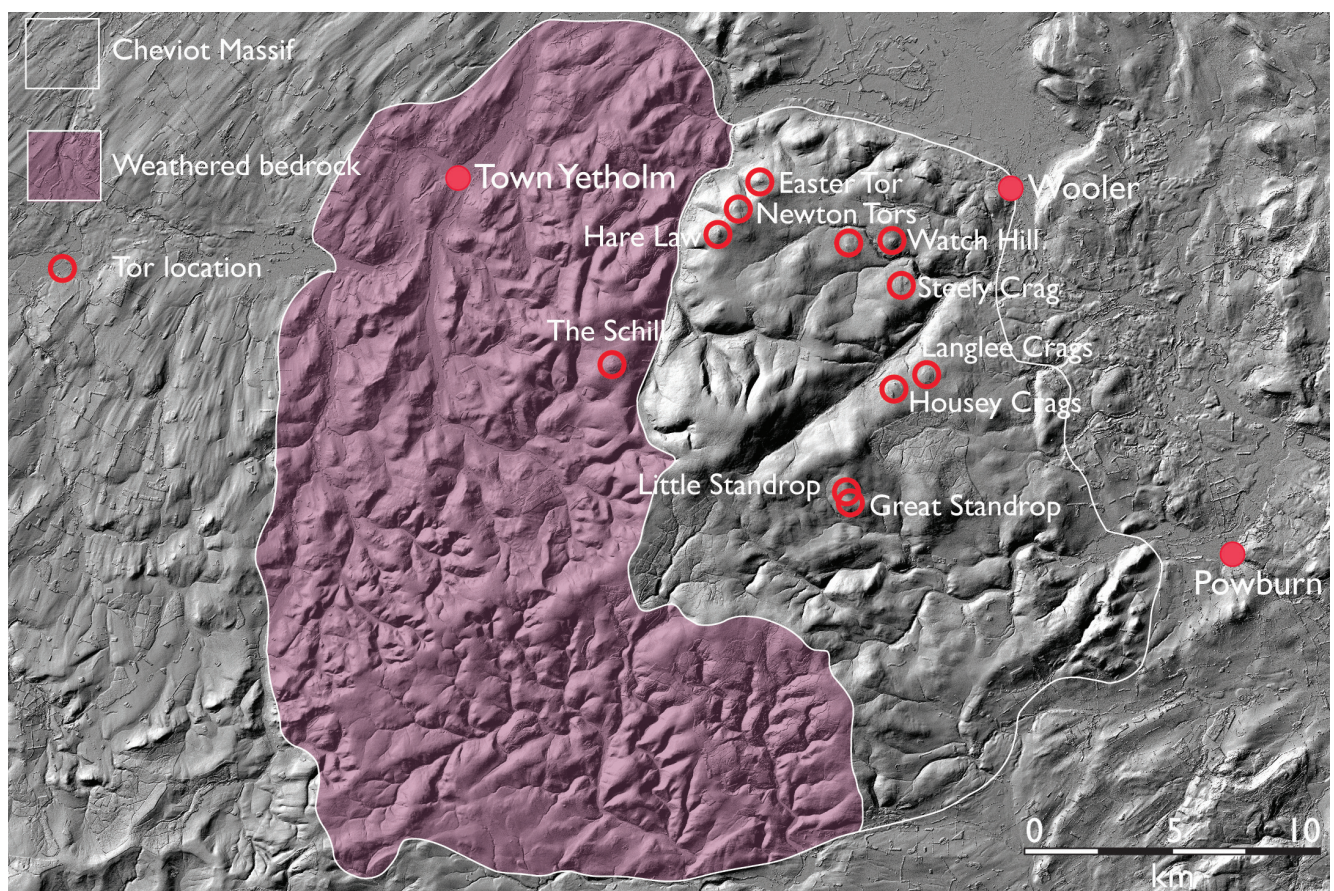
precipitation shadow of the western hills. Consequently ice build-up on The Cheviot would have been fairly limited, and in conjunction with the arid and cold climate this would have led to a subglacial regime characterised by 'cold-based' conditions (p. 57).

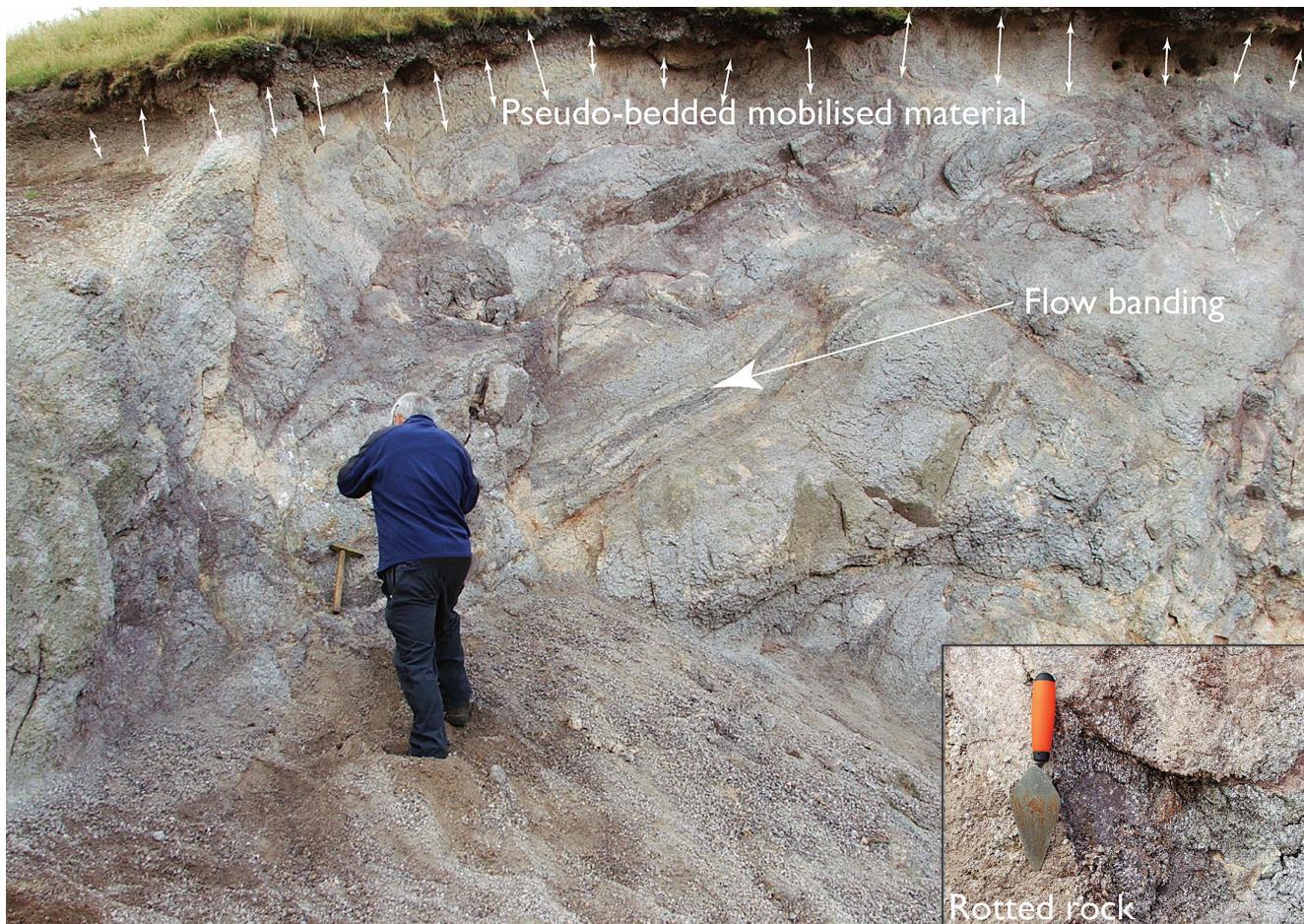
Bedrock alteration

In aerial view the overall character of the bedrock exposure in the Cheviot massif can be divided into two distinct types. The western part of the massif is characterised by slopes that are deeply incised by high density fluvial drainage networks. In the eastern part of the massif slopes are much more linear, and drainage density is significantly lower. The distinction in character between the two landscapes is largely due to the alteration of the bedrock in the west by significant *in situ* weathering. Few exposures of weathered material have been found to

date, however the landscape of the whole of the western Cheviot exhibits similar characteristics to areas where known saprolitic rocks occur in the north of the massif, where several metres of rotted material are to be found at surface. In the area around the valley of the Kale Water, south of Hownam [NT 7717 1640], the rocks are completely weathered to a clay deposit, which in parts may be more than 10 metres thick. The primary igneous textures are preserved, indicating that alteration occurred *in situ*. There are two main methods by which granites can be weathered: hydrothermal alteration, by which groundwater, usually under pressure, chemically alters the composition of surrounding rocks; and subaerial weathering. This involves long exposure to the elements, with rainfall seeping through the rock, causing the alteration of minerals, and removing the products of these reactions.

Distribution of in situ weathered bedrock and tor features in the Cheviot massif
(Hillshade image derived from NEXTMap® © Intermap Technologies Inc.)





Section in deeply weathered bedrock near Hownam; clearly showing the preservation of primary igneous texture

Tors

British tors have been the subject of much research throughout the 20th and 21st centuries. Throughout this period there have been two dominant theories of tor formation. A two-stage model, with deep chemical weathering prior to the Quaternary period and then removal of the products of that weathering by mass movement under periglacial conditions during Quaternary glacial periods. A one-stage model has also been proposed, with formation of tors during Quaternary glacial periods as a result of a combination of frost riving and mass movement under periglacial conditions.

The locations of tors appears to be controlled largely by association with the parts of the landscape that do not support weathered bedrock. All but one of the major tors occur in the eastern part of the Cheviot massif, with the best developed examples at Great Standrop, Langlee and Housey Crag.

The tor developed in the Cheviot Granite at Great Standrop. The residual mass of rock appears as a pile of rock slabs



Glacial meltwater channels

Large numbers of channels cut by glacial meltwater have been identified around the Cheviot massif. Most of these are related to the action of subglacial meltwater, as indicated by their 'up-and-down' long profiles, though some channels are clearly subaerially formed, being the result of extensive outflow of meltwater during deglaciation. These latter channels are associated with extensive spreads of glaciofluvial sands and gravels, forming sheets on valley floors, such as those found in the Ingram valley and the valley of the Kale Water.

Glacial till

There is very little glacial till to be found within the massif itself, with the majority of deposits being distributed around its ice-streamed margins. The small deposits that do exist are found as small lenses and smears of clast-dominated, coarse matrix, rubbly tills on valley sides and in hollows and valley floors.

Peat

Extensive areas of blanket peat have formed in the Cheviots in the cool, wet climate. Blanket peat forms on slopes up to 30%, so the flatter plateaux and summits of the hills and the lower more gradual slopes, as well as in the dips and saddles between more rounded summits, are the main locations for this habitat. Good examples are Cheviot summit plateau, the areas between Hedgehope and Combe Fell [NT 930 190] and Coldburn Hill and Hare Law [NT 903 245] as well as

Broad Moss north-west of Hedgehope [NT 960 215]. Where the slopes become steeper, the blanket peat ends and haggling is visible on the margins marking the transition to a heather/acid grassland mosaic on mineral soils.

Alluvial deposits

Alluvium is widespread on the floors of the Harthope, College, Kale and Upper Coquet valleys. These are the only significant rivers draining the massif, and their drainage pattern most likely reflects the dominance of bedrock faults across the Cheviots, rather than valleys created by glaciation. Therefore, in essence the drainage pattern is most likely inherited from pre-Quaternary times, and has undergone little alteration either during glacial times, or afterwards. The most extensive alluvial deposits are to be found in the valley of the Kale Water where modern alluvium overlies glaciofluvial deposits, laid down during retreat of the last ice to have covered the region at the end of Devensian time.

Influence on biodiversity

Quaternary deposits by their very nature and wide distribution have the biggest influence of any geological deposits on the biodiversity of the district. These deposits and the vegetation that they now support have however been substantially modified by humans and what we see now is only a snapshot in time. Future climate change and management will have a strong influence on biodiversity.

A meltwater channel draining north-eastward from Ewartly Shank [NT 9644 1470]



There is significant lateral discontinuity of different Quaternary units, which contributes to changing soils and ground conditions over very small geographical areas. Possibly the unit supporting the most diverse flora and fauna is Holocene peat. The internationally important Border Mires in the Hadrian's Wall area and other raised mires are home to a wide range of plant, insect and animal life including sphagnum mosses, sundews, bog rosemary, large heath butterfly and wading birds such as dunlin. The blanket peat habitats in the Cheviots and Cheviot fringe areas are generally less diverse but do support sphagnums, cottongrass and, at higher altitudes, cloudberry. Areas of till tend to have been cultivated over the centuries, and most of these areas are now pastureland and do not support significantly diverse ecosystems. The exceptions to this are the few remaining species-rich hay meadows (once more widespread). The free-draining soils overlying much of the glaciofluvial deposits in the Cheviot fringe have allowed widespread agriculture, hence much of the biodiversity there has been significantly modified by the actions of humans. Clearance of natural woodland and maintaining open ground by grazing has replaced shrub and woodland by moorland habitat across large areas. This habitat characterised by *Calluna* heather, with other dwarf shrubs such as bilberry, cowberry and bell heather is now considered important in its own right and sites such as the Simonside Hills and Harbottle Hills are considered internationally important. In other areas grazing has reduced the vegetation to a less diverse acid grassland mosaic. Large scale post-war planting of coniferous forests in some areas has replaced natural vegetation including areas of peatland, but restructuring and felling is reversing this in some areas.

Economic use

The extensive spreads of glaciofluvial and Holocene age alluvial sands and gravels in the district have encouraged a fairly high level of extraction in the past. The alluvial terraces of the Tyne are regular in depth and are predominantly composed of graded gravels, the finer material having been washed out. These terrace gravels tend to be primarily composed of Carboniferous sandstones with some lower Palaeozoic greywackes, with limestone and some igneous rocks. Extraction has taken place all along the Tyne from Gilsland in the west, to Crawcrook in the east, with numerous small-scale pits being worked predominantly in the alluvial terrace material. Possibly the most extensive working of the

glaciofluvial material has been at Prudhoe Gravel Works. The Milfield Fan is predominantly composed of sands and graded gravels. There have been extensive sand and gravel workings at Woodbridge Farm Quarry at Milfield since the 1960s, and this quarry is still in operation. The Lanton Quarry is set to continue working after Woodbridge Farm Quarry has closed, and in 2000 had estimated reserves of 1.8 million tonnes. Further to the south Branton and Low Hedgeley quarries have also produced significant yields of sand and gravel, though their operations are winding down, with the Branton site now having been largely restored to artificial lakes. At Thrunton the brick clay quarry continues to extract laminated glacial lake clay.

Traditionally, peat has been drained and cut for fuel in the district, but in recent years it has been extracted on a commercial basis and sold for horticultural use. Peat is currently extracted at two sites in Northumberland on the north-eastern margin of the district, Kemping Moss near Lowick and Greymare Farm near Belford. Extraction at a third site, Bell Crag Flow, within the National Park, has ceased and the site is being restored by blocking drainage ditches and removing self-seeded conifers. There is now a presumption against opening new peat extraction sites as the peat habitats are now recognised as being important for biodiversity, carbon storage and water retention.

Even though the Tyne valley has extensive sand and gravel deposits, it is clear from the scale of historical extraction that they have limited future potential. The deposits occur in narrow units (less than 500 metres lateral width), and are less than 10 metres thick in most places. Other UK sources of such material are more economically viable. By far the largest potential future source of sand and gravel resources remains the Milfield Fan. However the extent to which it has already been excavated may prevent further development due to fears over the complete loss of the feature. The Milfield Plain may prove to support thick sequences of glaciolacustrine (related to the glacial lake) muds and sands, of use to brick clay and sand resource industries. However, this area of high quality land is currently extensively farmed, and is beneath the eastern flank of The Cheviot, close to the National Park borders, and thus any proposed extraction may meet with local difficulties. The proximity of sites to the National Park renders the area sensitive to further large-scale resource extraction and stringent

planning and environmental conditions would have to be met in any proposals for future working of the sand and gravel deposits.

Conservation issues

The Quaternary deposits of the district are largely robust, and current farming and resource extraction practices have had little effect upon their overall distribution and stability. However future development of the Tyne valley floodplain and possible sand and gravel extraction could remove possible key sites and sections with the potential to lead to greater understanding of ice-sheet behaviour in the region. The glaciofluvial and river terrace sequences of the Tyne, around Haltwhistle and Hexham give clues to the late glacial and Holocene drainage history of the area, which is yet to be reconstructed. Future development of the Milfield Plain area with associated sand, gravel and brick clay extraction may begin to remove possible key sites and sections that may lead to greater understanding of ice-sheet behaviour in the region.

Wider significance

The Quaternary landscape of the district is one that has increasing significance for the earth science community. Understanding of ice-sheet behaviour is evolving rapidly. Our interpretation of deglaciated landscapes is now heavily influenced by modern polar studies, and this has led to our increased knowledge of the behaviour of the British ice-sheet. Using this increasingly complex model, inferences can now be made about the effects of past climate change on this dynamic ice-sheet, and also on the effects of sea level rise and subtle variations in internal glacial processes. The Hadrian's Wall country exhibits the classic landscape of a palaeo-ice-stream track, now recognised as being highly significant in the regulation of the mass balance of ice-sheet systems.

The Cheviot fringe area, with its extensive lake, fan and glaciofluvial deposits may provide significant opportunities for earth scientists to add vital pieces of information to our fragmentary record of the period during and immediately after the decline of the last great ice-sheet in Britain. The lake bed of palaeo-Lake Milfield is a potentially vital source of environmental data relating to the collapse and disappearance of the last great ice-sheet in the region, some 15 000 years ago. Lake sediments may contain records as diverse as pollen, diatoms, volcanic ashes or tephra and beetle and plant remains

that may give detailed and high resolution information regarding this critical period in recent Earth history. There are also gaps in our knowledge about the vegetational history and human impact upon it. Particular omissions in the record exist in the north and western parts of Northumberland. Examination of Quaternary deposits, particularly peat habitats, could yield important information. This links to the NNPA archaeological research agenda and should build on previous palaeoenvironmental research in the region.

The Quaternary landscape of the Cheviot massif appears to be very unusual in Britain. It is an upland area that has undergone glaciation during the Quaternary, most recently during the Devensian. However it still preserves features relating to the action of longer term, less physically dynamic processes, i.e. tors and deeply weathered bedrock. The preservation of these normally sensitive features in a landscape that has undergone glaciation is extremely unusual. Understanding why this occurs is a key challenge for future scientists, as it appears to stand contrary to accepted wisdom concerning glacial erosion in upland areas, namely that glaciers perform large amounts of geomorphological work throughout a glacial cycle. If the landscape of the Cheviot massif is inherited from an earlier period of Earth's history, then this assumption must be challenged.

Geological SSSIs

Quaternary of north-east England:

Cheviot Tors	[NT 956 215]
Humbleton Hill and Trows	[NT 951 275 and NT 963 283]
Roman Wall	[NY 715 667]

Fluvial Geomorphology of England and Wales:

Harthope Burn	[NT 961 230]
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Other related biological SSSIs

Roman Wall Loughs – glacial loughs including the terrestrialised Caw Lough, now a mire
Border Mires – SAC, internationally important mires
Otterburn Mires, Simonside Hills, Harbottle Moors and Cheviot SSSI all containing blanket and raised mires.

Mineral veins and minerals

Mineral veins are sheet-like bodies of mineral which occupy more-or-less vertical fissures or cracks in the surrounding rocks. The fissures are commonly faults. Veins may vary from less than a millimetre to tens of metres in width and comprise concentrations of minerals that may otherwise be extremely rare or widely scattered throughout the rocks. Some mineral veins are composed almost exclusively of one introduced mineral, though more usually a number of different minerals are present, commonly forming bands parallel to the vein sides. The minerals include metalliferous ore minerals generally accompanied by a variety of non-metallic minerals, known as 'gangue' minerals. Veins are commonly concentrated in groups in particular areas or geological environments and the term 'orefield' is often applied to such areas that have yielded commercially workable concentrations of ore minerals.

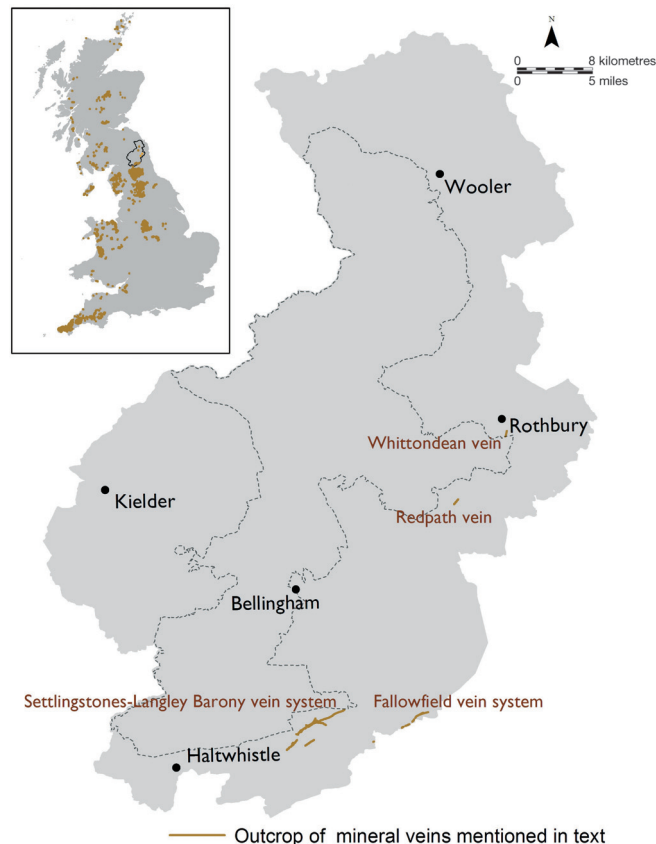
Vein minerals commonly occupy all available vein space and do not form well-shaped crystals. However, small cavities within the vein, known as 'vugs', may be lined with beautifully crystallised examples of the constituent minerals.

Mineral veins and minerals in Great Britain

Mineral veins of many different types, and with a wide range of constituent minerals, are found in many parts of Great Britain. Many of these have been important sources of metal ores and other associated economic minerals.

Mineral veins provide clear evidence of the circulation of large volumes of warm mineral-rich waters deep beneath the Earth's surface. By studying their form, distribution, mineral content and chemical composition it is possible to deduce much about their geological evolution and the environments in which they formed. Such studies not only contribute to interpreting the deposits of any one area, but are vital to understanding the nature and origins of comparable deposits elsewhere, thus helping to inform and guide exploration for similar deposits worldwide.

The distribution of mineral veins in the district; the inset map shows, highly simplified, the main areas in Great Britain where mineral veins occur



Mineral veins and minerals in the district

In common with most parts of Great Britain, no comprehensive inventory of minerals exists for Northumberland. However, a substantial number of minerals are reliably reported in the scientific literature from the district's mineral veins, as components of the rocks, and in a handful of rather specialised environments related to recent weathering processes.

Minerals in metalliferous veins

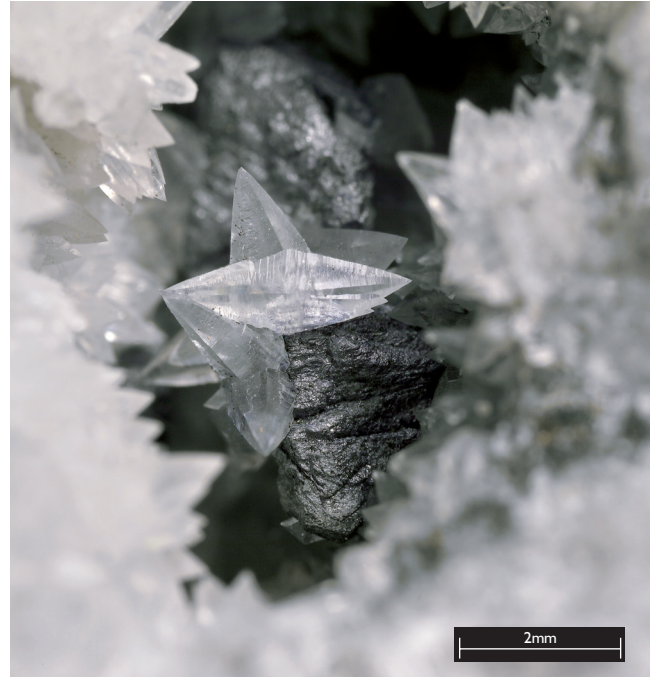
The veins found in the southern part of the district, generally to the south of Hadrian's Wall, occur within the outer zones of the Northern Pennine Orefield. Deposits within the central zone of the orefield, on the Alston Block, are characterised by an abundance of fluorite. In the outer zone, fluorite is typically absent, its place being taken by barium minerals, the most common of which



Witherite crystals from Fallowfield Mine

are baryte (barium sulphate) and witherite (a barium carbonate). Elsewhere in the world, witherite is a very rare mineral, but for reasons which are not yet fully understood it occurs in remarkable abundance in the North Pennines, and in particular in several veins in the Haydon Bridge area of the district.

Veins within the orefield mostly occupy normal faults, typically with a maximum displacement of only a few metres. Veins may be up to 10 metres wide, though most of those worked have been less than 5 metres. Non-metallic, gangue minerals such as baryte or witherite usually comprise most of the vein with ore minerals such as galena (lead sulphide) and sphalerite (zinc iron sulphide) forming a much smaller proportion of the filling. An important aspect of the deposits is the close relationship between the veins and the adjacent rocks. In hard rocks such as limestones, hard sandstones or the Whin Sill dolerite, veins may be comparatively wide and commonly stand almost vertically. Such areas of vein have generally been the most economically productive. In weak rocks such as mudstones, siltstones and soft sandstones, veins are typically narrow and inclined at a lower angle. Such lengths of vein are commonly barren and worthless. The interbedded nature of hard and soft rocks within the district,



Alstonite crystals from Fallowfield Mine

combined with the effects of this on faulting, have been conducive to the formation of mineral veins.

Although galena was the main metal ore extracted, few noteworthy specimens of this mineral are known from the district. However, the veins have long been celebrated for beautifully crystallised specimens of several minerals found lining vugs. Prominent amongst these are specimens of witherite. The Settlingstones and Fallowfield veins have provided some of the finest examples of witherite known and spectacular specimens are to be seen in most of the world's major mineralogical collections. In addition to witherite, Settlingstones Mine was a notable source of beautifully crystallised examples of baryte, together with much smaller amounts of strontianite (strontium carbonate) and niccolite (nickel arsenide), accompanied by small amounts of galena and ullmanite (nickel antimony sulphide). The Fallowfield Vein also has the distinction of being the source of some of the original, and finest, specimens of the rare double-carbonate of barium and calcium known as alstonite.

Sphalerite is locally abundant, particularly at Stonecroft and Langley Barony mines, where it is commonly found in the rather unusual pale brown banded variety known as 'schalenblende'.

The south of the district includes several other small veins which appear quite unrelated to those of the Northern Pennine Orefield. These include numerous bitumen-bearing calcite veins in the area of Ryal and Mootlaw quarries, galena-bearing veinlets associated with the contact of the Whin Sill at Divethill Quarry, and many narrow veins in the Whin Sill containing quartz.

North of Hadrian's Wall, the district includes very few mineral veins. Those which are known are generally of small size and, although locally tried as sources of economic minerals, have nowhere proved workable. They are widely scattered and cannot be regarded as forming part of an orefield. The main veins are those at Whittondean, on the northern slopes of the Simonside Hills, near Rothbury, and near Redpath in the Fallowles Burn in Harwood Forest. Although it is known that 19th century trials were made in these for lead ore, no workable ore was discovered. Although descriptions of the veins are rather meagre, they appear to have been very narrow and to have contained only small amounts of galena, mainly in a matrix of baryte. This latter mineral is locally present coating joints or forming very narrow veins in the Fell Sandstone in a few places in the Rothbury area.

Very limited and incomplete reports of galena-bearing veins from other parts of the district exist but little or nothing is known of their precise location or mineral content.

Hydrocarbon veins

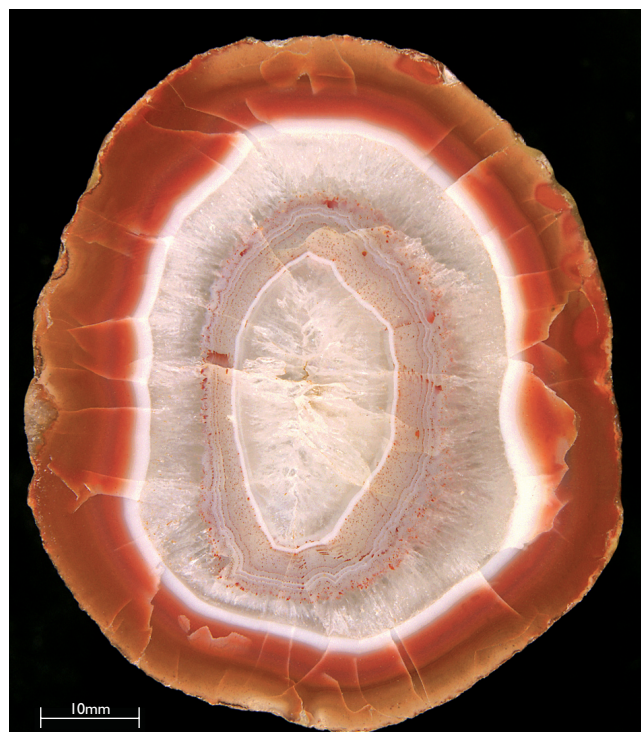
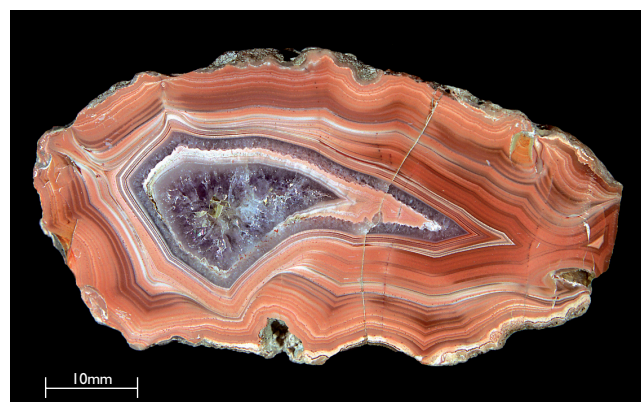
A distinctive feature of the Great Limestone of the Ryal area is the local abundance of calcite veins in which occur conspicuous concentrations of solid, black, brittle hydrocarbons. Very good examples are exposed from time to time in Mootlaw Quarry. Other examples may be seen in old quarries in the Great Limestone at Capheaton, Kirkheaton and Ryal. Solid hydrocarbons have been reported in very small amounts from the veins at Settlingstones and Fallowfield mines.

Minerals from the Cheviot volcanic rocks

The lavas of the Cheviot Volcanic Formation locally contain quartz-rich amygdales. Most commonly the quartz is in the form of beautifully banded agate, though in places more coarsely crystalline colourless rock crystal, purple amethyst and smoky varieties are also present, commonly in the central parts of agate amygdales.

Such weathered-out amygdales, commonly known as 'agates', may be found loose in any of the many rivers and streams which radiate from the hills, as well as in the fields that surround the lower slopes of the Cheviots. Numerous spectacular examples of agate have been recovered from the shingle banks of the River Coquet as well as from the river gravels worked at Caistron Quarry.

Cut and polished surfaces of agates, from amygdales in Devonian age lavas of Cheviot volcanic rocks, found as pebbles in river shingle. The upper photo is of a red 'fortification' agate with centre of crystalline amethystine quartz



Minerals associated with the Whin Sills

The metamorphosed limestones in contact with the Whin Sill at Barrasford Quarry locally contain concentrations of well-crystallised garnet and vesuvianite (a silicate of calcium, aluminium, iron and magnesium).

Although beautifully crystallised pectolite (hydrous silicate of calcium and sodium) is a characteristic mineral found lining joints in the Whin Sill of the Northern Pennines, its occurrence in the district is much more restricted.

Pectolite has been found coating joints and as amygdaloids (filling gas holes or vesicles) at Cawfields and Barrasford quarries. At the latter site it is locally altered to the rather uncommon mineral stevensite: a silicate of calcium, sodium, and magnesium.

Other amygdaloid-filling minerals at Barrasford include datolite (calcium borosilicate), calcite and quartz, both as brown 'smoky' quartz and purple quartz (amethyst).

The Haydon Bridge Dyke at East Mills Quarry, east of Haydon Bridge, was formerly known as a source of fine examples of amethyst found in cavities and veins in the dolerite. The quarry was filled several years ago and the site landscaped.

The iron sulphides pyrite and pyrrhotite, along with galena and sphalerite, are locally common as thin coatings on joints in the Whin Sill at Barrasford Quarry. Pyrrhotite is also common in contact-altered ironstone nodules at this locality. A few well-crystallised examples of galena have also been recovered from a veinlet adjacent to the contact of the Whin Sill with lower Carboniferous rocks at Divethill Quarry.

Authigenic minerals

An authigenic mineral is one formed in place in a sediment or rock either by replacing or displacing an earlier mineral. Impure siderite (iron carbonate), in the form of 'clay ironstone' is abundant as nodules scattered through the Redesdale Ironstone Shales (p. 38). These were extensively worked for iron ore during the 19th century in the Ridsdale and Bellingham areas.

A large specimen of haematite (an ore of iron) labelled as being obtained from the Bellingham area, Northumberland, is displayed in the Natural History Museum, London. However, its form is characteristic of west Cumbrian haematite and no reliable records of

haematite are known from the district. It is probable that this specimen is labelled in error.

Fine examples of coarsely crystalline celestite (strontium sulphate) of diagenetic origin have been found recently in some of the impure dolomitic limestones within the Ballagan Formation, exposed in the River Coquet at Barrow Scar. This is the first record of this mineral from Northumberland.

Holocene deposits

Certain Holocene deposits at Vindolanda have, over many years, yielded a remarkably rich variety of Roman artefacts. The same waterlogged, anaerobic conditions which have allowed the preservation of archaeological objects have favoured the formation of an abundance of the unusual iron phosphate mineral vivianite. This striking blue mineral encrusts many of the objects recovered from these deposits.

The oxidation of pyrite-rich rocks in colliery spoil heaps, in old workings and in natural exposures of the Coal Measures commonly results in the formation of bright yellow crusts of minerals such as jarosite (potassium iron sulphate). Acidic groundwater, produced by the same processes, may precipitate deposits of hydrated iron oxides, especially adjoining old mine entrances and in streams. Such deposits occur adjoining colliery spoil near Crindledykes.

An unusual deposit of well-crystallised gypsum (calcium sulphate) is today forming on the face of one of the Crindledykes quarries where water rich in sulphuric acid is reacting with the Great Limestone exposed in the quarry face.

Impact on the landscape

Unlike their counterparts further south in the main parts of the Northern Pennine Orefield, the vein outcrops of the present district have relatively little direct impact upon the landscape. Although there is little doubt that they were first discovered where exposed in streams or from the weathered soil content they produce, the veins themselves do not form recognisable topographical features. However, several veins have been worked on a significant scale, leaving a conspicuous legacy of spoil heaps and, in places, buildings.

The most notable spoil heaps are those associated with the Langley Barony, Stonecroft and Fallowfield mines.



Top left: Sign at entrance to Beltingham Nature Reserve; Top right: Spring sandwort; Bottom left, Alpine pennycress; Bottom right: Thrift

Most of the spoil heaps at the former Settlingstones Mine have been landscaped and although parts of the remaining coarse rock dumps are protected as an SSSI, they are becoming inconspicuous through increasing vegetation cover.

The fine brick-built Cornish pumping engine house at Stonecroft Mine is a prominent landmark and a row of miners' cottages, together with some of the ancillary mine buildings, converted for modern uses, remain at Settlingstones. A pipe to vent gas from the main underground workings is all that remains at Frederick Shaft, the main working shaft at Settlingstones, and the winding wheel from Ellen Shaft of the same mine has been erected recently at Fourstones as a monument to this industry. Meagre remains of mine buildings and ore-dressing facilities also remain at Langley Barony and Fallowfield.

Impact on biodiversity

As the vein outcrops within the district have little direct impact on the landscape, they similarly have a limited

impact on the biodiversity. Several mine spoil heaps, especially those which include accumulations of fine-grained tailings from ore-dressing processes, support plants that can grow in higher than normal concentrations of heavy metals; these plants are called metallophytes. In addition, such plants are found in some abundance growing on areas of Holocene river sediments at several locations adjoining the South Tyne. It is believed that waste from the main metal-mining and processing areas further south in the North Pennines, contaminated with lead, zinc, cadmium and sometimes barium, was released into the River Tyne and deposited downstream as fines, trapped amongst the river cobbles. Contamination levels vary according to which minerals were being mined and whether older contaminated deposits upstream have been reworked by the river. The most contaminated sites are sparsely vegetated with only the most metal-tolerant vascular plants present, but lichens, mosses and liverworts are abundant and may be highly diverse with as many as 30 lichen species per square metre. Many of the plants, including most of the mosses, leafy liverworts and larger

lichens are present because they can tolerate the metals and periodic drought and therefore do well in the absence of competition from vigorous grasses. Plant species such as spring sandwort (otherwise known as leadwort), alpine pennycress, Pyrenean scurvy grass, thrift, mountain pansy, Young's heleborine and moonwort occur on sites in the district.

Economic use

The galena-bearing veins of the district have been worked for lead ore at several places, mainly within the Haydon Bridge area of the Wall country. Some veins were certainly known, and probably being exploited, in the 17th century and perhaps at earlier dates, although there is no evidence of workings that date from Roman times. The main period of lead mining was during the 19th century. A general worldwide collapse in lead prices towards the close of that century resulted in the closure of most of the lead mines in northern England. Unlike the galena found in many of the lead veins of the main North Pennine Orefield, that found in the Haydon Bridge area typically had a very low silver content, and did not yield significant quantities of this lucrative by-product. Future working from any of the known lead deposits or other small veins in the district is very unlikely.

The discovery of substantial deposits of witherite as a gangue mineral in the Settlingstones and Fallowfield veins during the 19th century, together with demand for this mineral for the making of a range of barium chemicals, to some extent compensated for the worst effects of the collapse in lead mining. Witherite mining began at Settlingstones in 1873. From then until its closure in 1968 the mine became one of the world's main commercial sources of this mineral, and for long periods, including its final years, was the world's sole producer of this unusual raw material. The closure of Settlingstones Mine brought an end to witherite production worldwide.

Attempts to locate extensions to the Settlingstones and nearby deposits in the 1980s proved fruitless. Although proposals have been made within the past 20 years to recover baryte from the spoil heaps at Langley Barony, and witherite from those at Settlingstones, no extraction has taken place. In view of the toxic nature of the mineral, any resumption of witherite mining is unlikely, even if further reserves were to be identified.

Although sphalerite is abundant in parts of the veins worked at Langley Barony and Stonecroft (Greyside Mines), it was never recovered during lead mining. However, the spoil heaps at these sites were re-processed during the 1950s to recover the mineral.

Various attempts have been made to mine baryte or to recover it from spoil heaps, but little or none has ever been raised commercially. Further working of barytes within the district is very unlikely.

Clay ironstone nodules were extracted for iron on a substantial scale during the 19th century from quarries and underground mines in the Ridsdale and Bellingham areas.

Very small amounts of agate, collected from river shingles, have been employed as semi-precious stones in craft jewellery.

There are grounds for supposing that the lower Carboniferous rocks adjacent to the Stublick Fault System, at depth beneath the southern part of the district, could host metalliferous deposits analogous to some of those in central Ireland. Given the depth to the most promising horizons, and the difficulty in identifying exploration targets, exploration for such deposits must be considered unlikely.

The abundance of bitumen-rich veins in the Great Limestone of the Ryal area indicates that some of the Carboniferous rocks of the district may be source rocks for hydrocarbons and invites speculation on the potential for economic concentrations of oil and gas within central and southern Northumberland. Test drilling has taken place in several locations, most recently close to the A68 at Errington, although without discovering economically viable accumulations.

Conservation and environmental issues

No surface exposures remain in the district of any of the major metalliferous veins associated with the Northern Pennine mineralisation. The spoil heaps at Langley Barony, Stonecroft, Settlingstones and Fallowfield, provide the only remaining significant evidence of the worked veins and, in view of the very unusual nature of the mineral assemblages present, must be regarded as especially significant resources. They constitute important, and in some instances unique, resources of geological and mineralogical material and information. Fine examples of

several minerals, notably witherite and alstonite, have long attracted collectors: excessive collecting is known to have been a problem at parts of the latter site. Encroaching vegetation threatens the accessibility of both sites and may require attention in the near future. Landscaping or removal of spoil heaps, either as sources of low-grade aggregate, or as part of programmes of land reclamation, may pose serious threats to these resources.

Surface evidence of mineral veins elsewhere within the district is very meagre. Only very small amounts of spoil remain at Whittondean, though the site appears to be under no imminent threat. The site of the workings in Fallowlees Burn is heavily overgrown within the forestry plantation. Attempts should be made to locate and record any evidence of the workings when the timber is harvested.

Exposures of mineral veins in workings quarries are normally destroyed during the course of working. Where significant mineralisation is so exposed it is clearly desirable to see appropriate records made of the exposure together with collection of representative specimens. It is also important to ensure that such records and specimens are curated in a suitable permanent archive.

The small areas of mineral-related calaminarian grassland that are still in good condition are at risk of gorse colonisation from reduced grazing pressure, whether due to changes in agricultural practices or to a reduction of rabbit populations by culling or disease.

Environmental issues

Significant amounts of witherite which remain in the spoil heaps at both Fallowfield and Settlingstones may be regarded as significant contaminants which could be injurious, particularly to farm stock.

The attempts at Langley Barony and Stonecroft mines to re-process the spoil to recover the sphalerite have left substantial quantities of fine tailings. Like the spoil from lead working, these may be regarded as sources of heavy metal contamination.

Although surface subsidence over underground lead workings is generally uncommon, a striking example of this phenomenon occurs at Greyside Farm, near Newbrough. A number of farm buildings have here

collapsed into a crown hole developed above extensive stopes in Greyside Sun Vein.

Wider significance

The veins of the Northern Pennine Orefield comprise one of the world's finest examples of a zoned Mississippi valley type orefield. Accordingly, they have figured prominently in the evolution of ideas on the origins of such deposits. One of the many particularly important aspects of this orefield is the remarkable abundance of witherite and alstonite, which makes the area unique in the world. Although the orefield has long been a focus for research, very substantial opportunities remain for further important research. The spoil heaps from Settlingstones Vein remain an important, though increasingly meagre, source of representative material from this remarkable witherite deposit.

Fallowfield Mine shares, with Brownley Hill Mine near Alston, the distinction of being an original, or 'type', locality for alstonite, first recognised as a new variety of mineral in 1835. From the numerous specimens preserved in mineralogical collections it seems that alstonite was present in some abundance at Fallowfield which has yielded some of the finest known examples. Fallowfield remains one of the few localities known in the world at which this mineral may still be found. Parts of the spoil heaps, which are designated as an SSSI, include substantial amounts of the mineral.

The minor veins associated with the Whin Sills, although never likely to attract commercial interest, offer important research opportunities for furthering understanding of the emplacement of this major intrusion.

The excavations at Vindolanda provide one of the best recorded occurrences of vivianite in British Holocene deposits.

Geological SSSIs

Mineralogy of the Pennines:

Fallowfield Mine	[NY 936 675]
Settlingstones Mine	[NY 849 688]
Stonecroft Mine	[NY 854 688]

NWT Reserve

Beltingham Shingle

Geological structures

Geological structures are features within the rocks produced by distortion resulting from Earth movements. Such features include inclined, or dipping, rocks, folds and faults. They occur at a variety of scales from millimetre, metre and decimetre scale in local outcrops to regional kilometre scales affecting large tracts of the countryside. They may be very simple or highly complex structures, depending on the degree of distortion suffered by the rocks and their structural evolution over geological time.

Geological structures In Great Britain

Geological structures, at all scales, are ubiquitous through Britain and an appreciation of geological structures is vital to understanding the Earth processes that have shaped the landscape. The interpretation of large-scale regional structures allows geologists to interpret the geological evolution of the nation, to understand linked processes of sedimentation, volcanism, mountain building and erosion, and to construct palaeoenvironments. In outcrop, the measurement of smaller visible geological structures enables the overall large structural evolution of a region to be deciphered. Such observations and deductions are fundamental to making geological maps, in predicting, exploring for, and working mineral deposits, including groundwater resources, and in the design of major civil engineering projects.

Geological structures in the district

The structures present in the rocks of Northumberland National Park and the surrounding areas can be attributed to three main events in the geological evolution of the area, namely, the Devonian Caledonian Orogeny, Carboniferous regional extension and subsidence, and late Carboniferous compression related to the Variscan Orogeny.

By far the biggest influence on the regional scale geological structure of the district can be attributed to Carboniferous extension and subsidence, which produced the blocks and basins that divided northern England into major structural units (p. 21). The Stublick–Ninety Fathom Fault System, which crosses

the extreme south of the district, running eastwards from south of Haltwhistle, through Plenmeller Common to Stublick Moor, marks a line of major break-up at the southern margin of the Northumberland Trough. Subsidence within the trough was most intense in the south close to the fault system and diminished northwards. As a result the trough has a strongly asymmetric shape and the Carboniferous succession deposited in it thickens and dips southwards to south-eastwards. The best examples of southerly-dipping strata are to be seen the Carboniferous exposures of the Wall country where the rocks are inclined by up to 20°.

To the south of the Stublick–Ninety Fathom Fault System lies the Alston Block; a major structural unit roughly coincident with the present day Northern Pennines. During Carboniferous subsidence, the block remained relatively elevated, underpinned by the buoyant Weardale Granite, and subsided much less than the adjacent Northumberland Trough. As a result, the Carboniferous succession deposited on the Alston Block is significantly thinner than that of the trough and the strata today remain roughly horizontal.

The regional block and basin structure of the district was further modified by late Carboniferous Earth movements related to the Variscan Orogeny. The Alston Block and Northumberland Trough were regionally uplifted and locally faulted and folded; at the surface today, the late Carboniferous Westphalian Coal Measures of the trough are juxtaposed against the older Namurian sandstones of the block across the Stublick Fault. Northern Northumberland was raised into a considerable dome with the Cheviot massif at its centre. North-east of The Cheviot, the surrounding rocks dip northwards, towards the Tweed Basin, to meet the rocks dipping southwards from the Southern Uplands and form a regional 'down-fold' known as a syncline. To the east, south and west of The Cheviot, the dip is fairly constant and away from the massif.

The Cheviot massif presented a rigid block against which the softer Carboniferous rocks were compressed and buckled to form localised and highly asymmetrical folds. Good examples can be seen at Lemmington, west of Alnwick, at Holburn west of the Kylee Hills and, outside the district, on the coast at Scremerston where the Eelwell Limestone has been pushed over towards the west. An exceptional example of folding is a powerful

faulted 'up-fold' – or anticline – known as the Holburn Anticline, that runs along the east of the Cheviots for about 12 miles. This large structure locally elevates the Fell Sandstone as an escarpment, forming a barrier between the Cheviot Hills and the coastal plain.

Geological structures related to the earlier Caledonian Orogeny are restricted to the Silurian rocks of the district. These strata always appear strongly inclined and often tightly folded. They can be seen near the head of the Rede valley (at the road cutting above Catcleugh Reservoir), in the Canker Burn (a tributary of the Cottonshope Burn) and in the headwaters of the River Coquet (the Coquet Head Inlier). The Silurian sediments are typically very similar in appearance throughout the succession. This makes their structure somewhat hard to elucidate as there are no distinctive marker horizons within the sequence; minor folds are difficult to identify. It is sometimes possible to identify overturned sequences using sedimentary structures within the steeply dipping beds, and, depending on the density of sedimentary structures and the amount of exposure, it is sometimes

possible to position a fold axis to within a few metres, though in areas of poor exposure there is a wider margin of uncertainty. Several fold axes have been tentatively positioned, most notably a syncline south of Makendon.

Across the district the large-scale regional structure is further complicated by smaller scale folds, faults and fractures. An excellent example of a small monoclinical (one sided) fold in the Great Limestone is exposed in the eastern quarry at Crindledykes. Small localised anticlines and synclines, known locally as 'rolls', are common in the limestones throughout the district. One such example may be seen in Mootlaw Quarry where the great limestone is folded into an impressive syncline; structural deformation that appears not to have affected the overlying mudstones.

In addition to the major Stublick–Ninety Fathom fault System, numerous smaller scale faults cut the rocks of the district. These vary in scale from those with a displacement measurable in centimetres, to some with displacements of tens of metres. The direction of almost

Synclinal fold formerly exposed in the Great Limestone at Mootlaw Quarry. Note how the bedding in the upper part of the mudstones overlying the fold is apparently unaffected



all the faults with displacements of ten metres or more is east-north-east. Notable examples are the large Swindon Fault through Rothbury, and those that cross the head of Redesdale, from the southern edge of the Cheviots to the North Tyne and beyond. Small faults are occasionally exposed in working quarries but good natural exposures are rare, although the position of these faults, and their effect upon the continuity of outcrops of geological units is conspicuous locally in the landscape and is clearly apparent on geological maps. In the Haydon Bridge area, in the south of the district, small scale faults provided pathways for late Carboniferous/early Permian mineralising fluids. These mineralised faults, the only significant examples within the district, are termed veins and form an outlying part of the North Pennine Orefield (p. 73).

Joints are fractures along which there has been no displacement in the plane of the fracture. They are often regularly spaced and follow distinct trends through the rocks. They are extremely common in most of the limestones and sandstones of the district. The best examples of jointing within limestone can be seen in many of the small quarries of the Wall country. Here the joints usually run in two, roughly perpendicular, directions and, along with the bedding, divide the limestone into regular rectangular blocks.

In many intrusive igneous rocks joints form as the molten rock cools and crystallises. These joints are particularly conspicuous as they form regular patterns that divide the rock into hexagonal columns running perpendicular to the cooling surfaces. This style of jointing, known as columnar jointing, is spectacularly displayed in many exposures of the Whin Sills in the Wall country.

Impact on the landscape

Some of the district's most striking landscapes directly reflect the geological structure of the underlying rocks. The pronounced 'cuesta' landscape of the Wall country, with steep north-facing scarp slopes, and more gentle southerly dip slopes, mirrors the inclined alternating beds of resistant limestones, sandstones and the Whin Sill dolerite, with interbedded layers of weaker mudstones and siltstones. The change in the direction of the regional dip of the strata of the district, from a predominantly southerly direction west of the River North Tyne, to a predominantly easterly direction east of it, is reflected in the marked change in direction of the ridge features in

the landscape. The abrupt termination or lateral displacement of ridges often identifies the position of faults that locally disrupt these trends.

The almost horizontal sandstone beds south of the Stublick–Ninety Fathom fault System locally give rise to a landscape with rather flat-topped hills, in places with evidence of terracing on their sides marking alternations of beds of differing resistance to weathering.

The area immediately east of the Cheviot massif provides a striking example of the way in which topography is affected by structural geological factors. The Fell Sandstone, located on the faulted northeast limb of the Holburn Anticline, forms a rugged west-facing scarp overlooking the Wooler valley. The scarp acts as a drainage barrier separating the Cheviot Hills from the sea, and deflecting the drainage of local rivers, such as the Till, to the north. In the Cheviots, the long straight valley of the Harthope Burn marks the line of the Harthope Fault.

Small-scale geological structures influence landscape on a local scale throughout the district. Near vertical rock faces in cliffs and gorges are often the result of the weathering of joints and faults. Many examples can be found along the course of Hadrian's Wall, where joints and faults in the Whin Sill dolerite have been exploited by local drainage, and in the River Allen gorge, where the river has exploited major fractures within the hard sandstones.

Economic use

The mineral veins of the district occupy faults, and an understanding of the geological structure has lain at the heart of successful mining and prospecting. This understanding pre-dates the emergence of geology as an organised science, although the earliest miners undoubtedly understood and applied many of the concepts and principles of modern structural geology.

Geological structures place constraints upon the mining and quarrying of some rocks and minerals. This is especially true where faults displace, and thus effectively limit, the extent of workable rock units.

Anticlinal folds and faulted successions at depth may act as reservoirs, for hydrocarbon deposits. The geological structure of the Carboniferous rocks north of the Stublick Fault has invited speculation on commercial hydrocarbon

potential. Geophysical interpretations, in part resulting from seismic investigations, have identified structures at depth which invite exploration as potential hydrocarbon reservoirs. A structure beneath the Hadrian's Wall area was investigated by drilling a deep borehole in the winter of 2004-5 at Errington, north of Corbridge.

Conservation issues

Major landscape features determined by the larger geological structures, for example the 'cuesta' landscape of the Wall country, are generally robust in conservation terms. Exposures of structures such as folds and faults are comparatively few and are typically restricted to working or abandoned quarries. Some of these features could be readily damaged or destroyed by inappropriate restoration of old workings. Opportunities may exist for conservation of suitable examples of these features in restoration plans for working quarries. A number of very striking folds have been exposed, and subsequently destroyed, during the working of the Great Limestone at Mootlaw Quarry and the Stublick Fault was exposed briefly during the operation of the Plenmeller opencast coal site. Thus, recording the features by photography or clear field description is important.

Monoclinical fold in the Great Limestone at Crindledykes Quarry

The spectacular fold in the Great Limestone at Crindledykes forms part of an NWT Nature Reserve.

Wider importance

The Stublick–Ninety Fathom fault System is a fundamental feature of the geology of northern England, in part inherited from the now deeply buried Iapetus Suture, and has influenced the geological evolution of the region since at least Carboniferous times.

The structures exposed in the Wall country are a surface expression of the southern part of the Northumberland Trough, and thus give important clues to the regional structure of this major geological unit, and the fault system to the south.

The mineralised faults in the Haydon Bridge area comprise an outer portion of the Northern Pennine Orefield, and contain features of international importance in understanding orofields of this type.

Geological SNCIs

Crindledykes



Fossils and palaeontology

Fossils are the preserved remains of animals or plants. Most commonly only the hard shells or skeletal parts of an animal, or the most durable parts of plants, are preserved as fossils. In some circumstances the original soft animal or plant tissue may be preserved, but these are very rare indeed.

Trails, tracks, burrows, worm casts and feeding traces of a variety of animals in soft sediments are commonly preserved, and in some environments the imprints of soft-bodied animals may also be preserved. The term trace fossil is applied to such remains.

Palaeontology is the study of ancient life. The recognition of distinctive fossils, and fossil assemblages, is an essential tool in the identification, relative dating and correlation of rock units. Palynology is the study of fossilised plant remains. In common with animal fossils, these remains allow identification and relative dating of the strata, but are also essential for identifying palaeoenvironments that are conducive to the formation of fossil fuels including coal, oil and gas. Palaeoecology is the study of the associations of coexisting fossil species. Like modern ecology, this enables interpretation of contemporary environments and ecosystems. Palaeoecological interpretations can be made from many fossil assemblages, but most valuable are those in which the fossilised organisms are preserved in their life positions as complete fossilised ecosystems.

Palaeontology and palaeoecology together offer important links between geo- and bio-diversity. It is worth recalling that the vast majority of biological species are extinct and reside within the fossil record.

Fossils in Great Britain

Fossils of one form or another can be found in virtually all of the sedimentary successions throughout the United Kingdom, and some unique igneous and metamorphic successions. Some sequences are relatively barren and may only contain fossils of microscopic size (microfossils), whilst in others fossils clearly visible to the naked eye (macrofossils) and of many different species can be found in abundance.

One method for the subdivision of rocks, biostratigraphy, is based on the identification of key fossils and fossil assemblages, and the recognition of how these change with time through successions of strata. Such biostratigraphical 'zoning' by means of fossils assists identification of strata where the sequence is not otherwise clear and acts as an additional check on correlations based on similar rock types. Correlation of strata using this approach allows relative dating of sequences and enables comparisons to be made between areas of the same age, but composed of dissimilar rocks. Many fossil localities throughout the United Kingdom are key to recognising specific worldwide events in the geological history of the Earth and positioning the boundaries between different geological periods and era. These sites, along with similar sites in other countries, are used to correlate geological strata the world over.

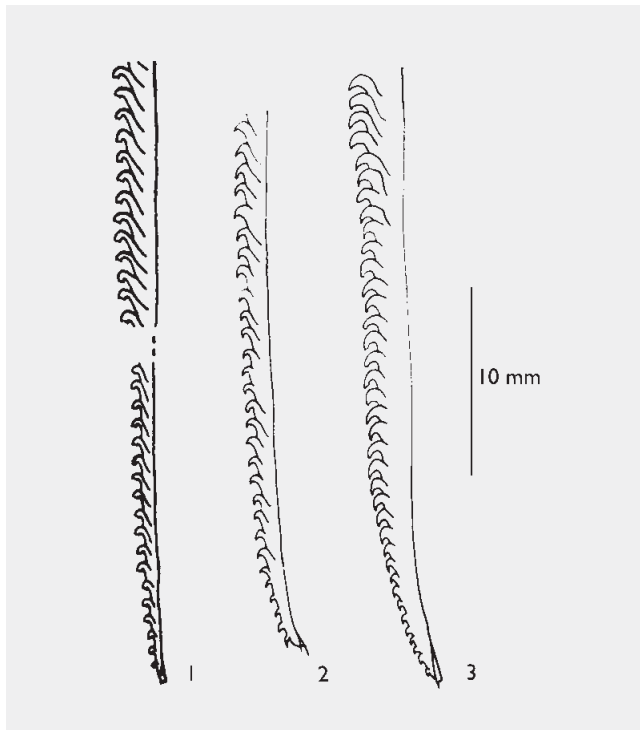
Fossils in the district

Detailed lists of the fossils recorded from the district may be found in the scientific literature, including many of the references cited in the bibliography. In addition, many large collections of fossils from the district are held in the collections of BGS and in museums (p. 104).

Fossils of Silurian age are the oldest to have been found in the rocks of the district. Although relatively rare in the district, sufficient graptolites have been found in the Coquet Head Inlier to form an assemblage diagnostic of the top of the *Monograptus riccartonensis* zone of Wenlock age. This has allowed the strata to be correlated with sediments in the nearby Riccarton and Hawick inliers. Other sites where Silurian fossils have been noted include the Lower Ramshope Burn.

Fossils recognised within the Coquet Head Inlier include: *Monograptus priodon*, *Monograptus flemingii*, *Pristiograptus meneghini*, *Monograptus radotinensis*, *Monograptus flumendosae*, *Atrypa* sp., *Orthoceras* sp., *Monograptus* sp. and *Helminthoida* sp. (trace fossil).

The Carboniferous rocks in the district contain finely preserved examples of many of the principal fossil groups, such as algae, sponges, foraminifera, brachiopods, molluscs, gastropods, ammonoids, goniatites, echinoderms, crinoids, corals, bryozoans,



Sketches of some characteristic graptolites from the Coquet Head Inlier. 1 *Monograptus priodon*, 2 *Monograptus riccartonensis*, 3 *Monograptus flemingii*

ostracods and plants. Whereas such fossils may be widely scattered through many of the rocks, a number of localities within the district are notable for concentrations of one or more fossil species. The following are particularly important:

Tipalt Burn [NY 659 661 – NY 687 683], in the west of the district, exposes fine sections through a particularly fossiliferous portion of the Lower Bankhouses Limestone. The nature and occurrence of the rich fauna of cephalopod molluscs, echinoderms, bryozoans, corals and brachiopods has invited comparison with the Carboniferous reef limestones of the Craven area of North Yorkshire. The site is today scheduled as an SSSI for its palaeontological importance.

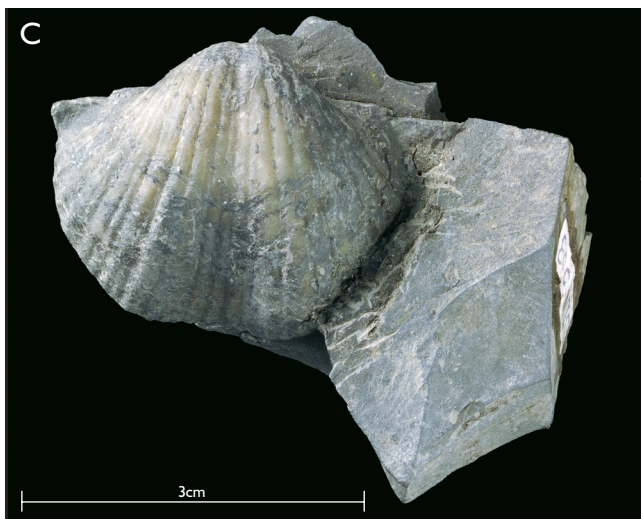
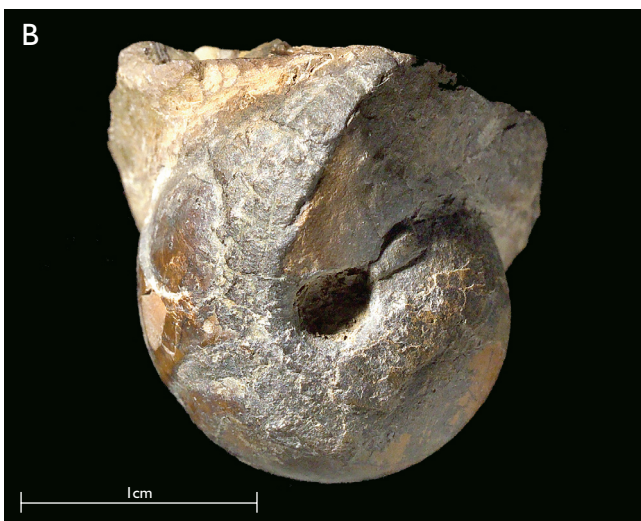
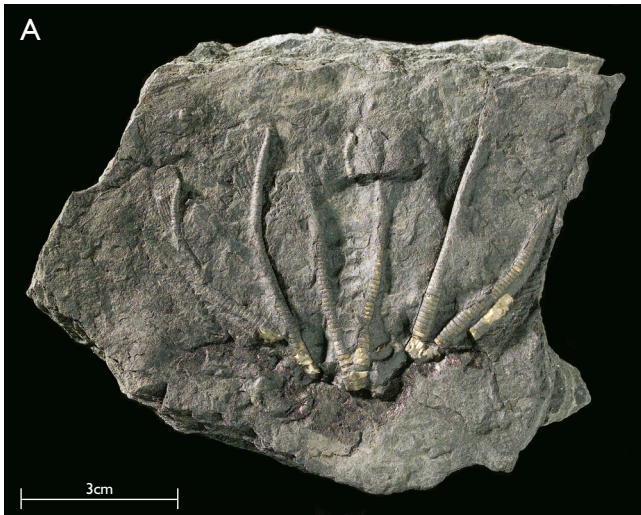
The **Redesdale Ironstone Shale** is renowned for the rich diversity and fine preservation of its fossils. One band in particular within the deposit contains an exceptionally well preserved molluscan fauna. Redesdale Ironstone Quarries SSSI [NY 895 833] is one of the richest faunal localities in Dinantian strata in Britain.

The long-disused **Brunton Quarry**, near Chollerford [NY 929 700], which displays a section in the basal Namurian Great Limestone, is scheduled as an SSSI for its palaeontological importance. The Chaetetes Band, in the lowest 1.5 metres of the limestone, contains superbly preserved reef-like encrusting mats of the sponge *Chaetetes depressus*, accompanied by colonial corals and a variety of brachiopods and bivalves preserved in life position. It is a superb example of a Carboniferous tropical sea floor community – or complete ecosystem – fossilised *in situ*. The quarry is additionally noteworthy as the type locality for the alga *Calcifolium bruntonense*, a species restricted to the Great Limestone, in a bed known as the Brunton Band.

The **Greenleighton Quarry** SSSI [NZ 034 920] is of importance for the rich marine shell faunas contained in the Great Limestone and the overlying shales, including the type material *Pleuropugnoides greenleightonensis*. Nodules occurring just above the Great Limestone have yielded specimens of the goniatite *Cravenoceras leion*, thus proving the Great Limestone to be at or very close to the base of the Namurian, and ending the controversy over its precise stratigraphical position.

Trace fossils in sandstone at Hindleysteel Quarry, Henshaw Common





A – Crinoid, *Woodocrinus* sp.
B – Goniatite
C – Brachiopod, *Spirifer bisulcatus* group

In **Black Pasture Quarry** [NY 932 699], sandstones above the Great Limestone locally contain abundant specimens of the brachiopods *Schellwienella crenistria*. The abandoned sections of the quarry also expose beautifully ripple-marked surfaces of sandstone on which well-preserved worm casts are locally conspicuous.

At **Mootlaw Quarry**, near Ryal [NZ 024 750], the shales that overlie the Great Limestone are notable for a rich and varied fauna of brachiopods, molluscs, gastropods, crinoids and goniatites. Of particular interest is the presence of the goniatite *Cravenoceras* cf. *lineolatum*, an important marker fossil in the Namurian rocks of northern England. The shales have also yielded an almost complete, fully articulated, crinoid: such fossils are almost invariably found in a fragmentary condition.

Conservation issues

Like all surface exposures, well-exposed sections of highly fossiliferous rock are vulnerable to deterioration through weathering and the growth of vegetation. Whereas the collecting of fossils, especially from *in situ* exposures, is a real threat in many parts of Great Britain, there is little or no evidence for such activities damaging fossil-bearing sites in this district.

The recovery, by collectors and research workers, of fossil specimens from active quarry workings can make a valuable contribution to the preservation and conservation of important material, providing specimens and accompanying documentation are deposited in an appropriate museum or in national collections.

Wider significance

The fossils within the district's rocks give invaluable evidence of contemporary environments and ecosystems across northern England and Europe, and enable correlations and comparisons to be made with rocks of similar age and type elsewhere in Britain and across the world.

The palaeontologically distinctive Chaetetes and Brunton bands, within the Great Limestone, are of considerable importance in enabling detailed the correlation of parts of the Carboniferous sequence across a wide area of northern England. The fossils within the Great Limestone and overlying mudstone have been significant in determining the position of the base of the Namurian stage in Europe.

Mines and quarries

Mineral products have been worked in the district since at least Roman times. Minerals are important natural resources that make an essential contribution to the nation's prosperity and quality of life. Their extraction contributes to the local economy through direct employment and as raw materials for industry and construction. The district's varied mineral resources and localities at which they have been worked are an important aspect of its geodiversity. Exposures in mines and quarries provide unique opportunities to see and study local rocks. Mineral exploitation has contributed, and continues to contribute, much to the district's essential character and landscape. Mineral working can, however, cause major disturbance to the environment and people's living conditions. Whereas its impact on the landscape has been generally less than in the nearby Northumberland Coalfield and Northern Pennine Orefield, the legacy of mining and quarrying is conspicuous in several places. Mining has ceased, but quarrying continues to be an important part of the local economy, though modern planning constraints greatly reduce the industry's most obvious visual impacts.

Whilst strict conditions and controls are applied to the approval and operation of all mineral operations in the UK, the special status of National Parks requires mineral planning applications to be subject to the most rigorous examination and operations to be planned and operated with particular sensitivity. A Minerals Local Plan provides the policy framework for the extraction of minerals in the Northumberland National Park and was adopted in 2000. This will, in due course, be replaced by a Local Development Framework.

The mode of occurrence of the rocks and minerals of the district, and their economic contribution to it, are described in earlier sections of this report. The following rocks and minerals are known to have been worked in the district:

- Ores of iron, lead, and zinc
- The non-metalliferous minerals witherite, barytes
- Limestone, sandstone, dolerite and other igneous rocks, coal, fireclay and brickclay, peat, sand and gravel.

The contribution of mineral extraction to the geodiversity of the district is considered below:

Abandoned quarries

Abandoned quarries may be regarded as essential and distinguishing features of the present day landscape. The diverse geology of the region has meant that it has a long history of quarrying that has taken a range of forms. Small quarries clearly utilised for building stone are found spread widely across the region. 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. These all used simple technology, and it is difficult to date their use.

Stone was not only used for building, but also a range of other products including millstones and troughs. Many millstone quarries are known, often only through map or documentary evidence, though at some sites, such as Beanley Moor and Harbottle Crags, semi-completed millstones are still visible.

Limestone was also often burnt for field lime, and it is common to find quarries associated with limekilns. Substantial quarries and kilns can be seen, for example at Tossen, Greenchesters, near Walltown and at Crindledykes. A Roman limestone quarry and kiln have been identified near Greenlee Lough. Improved communications and transportation made local kilns uneconomic but limestone was still being burnt in the 1950s in the Redesdale Limestone quarries at Buteland [NY 880 816].

Certain geological units have attracted particular economic interest; numerous substantial quarries mark the outcrops of the Great Limestone, the Whin Sill, and several of the Carboniferous sandstones. Opened in 1876, Walltown Quarry, on the Whin Sill, was the largest 'whinstone' quarry on Hadrian's Wall. It and the rather smaller Cawfields Quarry to the east have been restored and landscaped while maintaining faces exposing the Whin Sill and adjacent rocks.

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. In some instances their biodiversity interest may be significantly greater than their geodiversity interest.

Abandoned quarry floors and faces offer a variety of substrates for specialised plant communities, including sites for lichens and other lower plants. They 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. 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.

Active quarries

Igneous rock, limestone, sandstone, peat, and sand and gravel are worked in the district. Active quarries provide fresh and constantly changing sections through the deposits being worked. They therefore provide some of

Extracting and crushing rock for aggregate at Barrasford Quarry; the near-horizontal bedded rocks behind the excavator are metamorphosed Oxford Limestone



the finest opportunities to further understanding and appreciation of the area's geodiversity. With appropriate planning for after-use, quarries may also be developed as important future assets for biodiversity and recreation and can become considerable assets to the area's natural heritage. Active quarries offer opportunities to demonstrate the working techniques and the 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 conservation of important geological features.

Dolerite ('whinstone') from the Whin Sill is worked as an important source of roadstone and large blocks are recovered for use as armour-stone. Four large quarries today work the main sill at Keepersields, Barrasford, Swinburne and Divethill. Porphyritic rhyolitic rock at Harden Quarry within the National Park is one of the few places in the UK where naturally red stone can be obtained and is particularly suitable for specialised use in road surfaces.

The Great Limestone is extracted at Mootlaw Quarry, near Ryal, and metamorphosed Oxford Limestone is worked adjacent to the Whin Sill at Barrasford Quarry. Crushed rock aggregate and roadstone are the main products. The working practice adopted at Mootlaw is to partially backfill the worked-out portions of the quarry with overburden and quarry spoil and then to return the land to agriculture. Similar practices are adopted at Barrasford.

Sandstone is worked primarily for building stone. Small amounts, mainly of waste material, are also sold for aggregate. Northumberland produces particularly high quality building stones, which have been used for prestigious buildings both locally and nationwide (p. 91).

Peat is currently extracted at two sites in Northumberland on the north-eastern margin of the district, Kemping Moss near Lowick and Greymare Farm near Belford.

Sand and gravel in the alluvial deposits of the River Tyne have been worked from comparatively small pits. The sand and gravel deposits in the area between Wooler and Milfield are, together with the Powburn area, amongst the highest quality reserves in Northumberland and continues to be extracted at a number of sites in that area. These include Roddam Quarry on the eastern edge of the National Park and Woodbridge Farm.



Roadway in underground workings of the Little Limestone Coal at Blenkinsopp Colliery photographed in 2002 © Joel Porter

Underground mines

Underground mining in the district ceased with the closure of Blenkinsopp Colliery in 2002. The majority of coal workings were of small scale, consisting of open cast workings on the seam outcrops, bell-pits, shallow shafts and adit levels which mainly worked coal to depths of 100 metres or less. All the coal workings are now believed to be flooded and inaccessible, but documentary material including illustrations and photographs is important in appreciating the place of coal mining in the geodiversity of the region. The Romans almost certainly worked coal, particularly from those seams which crop out close to Hadrian's Wall. Documentary records exist of coal working in the 13th century and by the early 1620s, coal was being mined on a commercial basis in the Grasslees valley between Elsdon and Hepple.

Substantial underground mining of lead and later witherite took place in the south of the district. The closure of Settlingstones Mine in 1968 brought an end to witherite production worldwide (p. 73). Some buildings remain as evidence of the Settlingstones and adjacent mines; the underground workings are inaccessible, but material extracted can still be found on the spoil heaps.

Spoil heaps

The district includes a varied legacy of mineral wastes in the form of spoil heaps from quarries, mines or mineral processing plants, including former metal smelting operations. Such spoil heaps typically comprise the geological materials discarded as waste from the deposit worked. Inevitably most spoil heaps also contain examples of the materials worked. As the area's underground mines are no longer accessible for study, spoil heaps provide a unique source of material evidence for the materials worked, or penetrated, in the mine workings. Exposure to weathering in spoil heaps may enhance the value of the materials present. 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. New mineral species may be forming within spoil heaps, particularly in waste materials from former smelting operations, as a result of near-surface (supergene) processes.

Spoil heaps are locally important elements in the area'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

clues to the presence of former workings. Spoil heaps may be rather vulnerable elements in the landscape. Removal of rubble for earthworks or track-making, or reclamation of spoil heaps may damage them. Such reclamation activities may include tree planting or top-soiling of the heaps, both of which effectively render the materials contained within the spoil 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. 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 plants.

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. Spoil heaps may offer important potential for sustainable educational and recreational collecting. Excavation of a spoil heap offers important opportunities

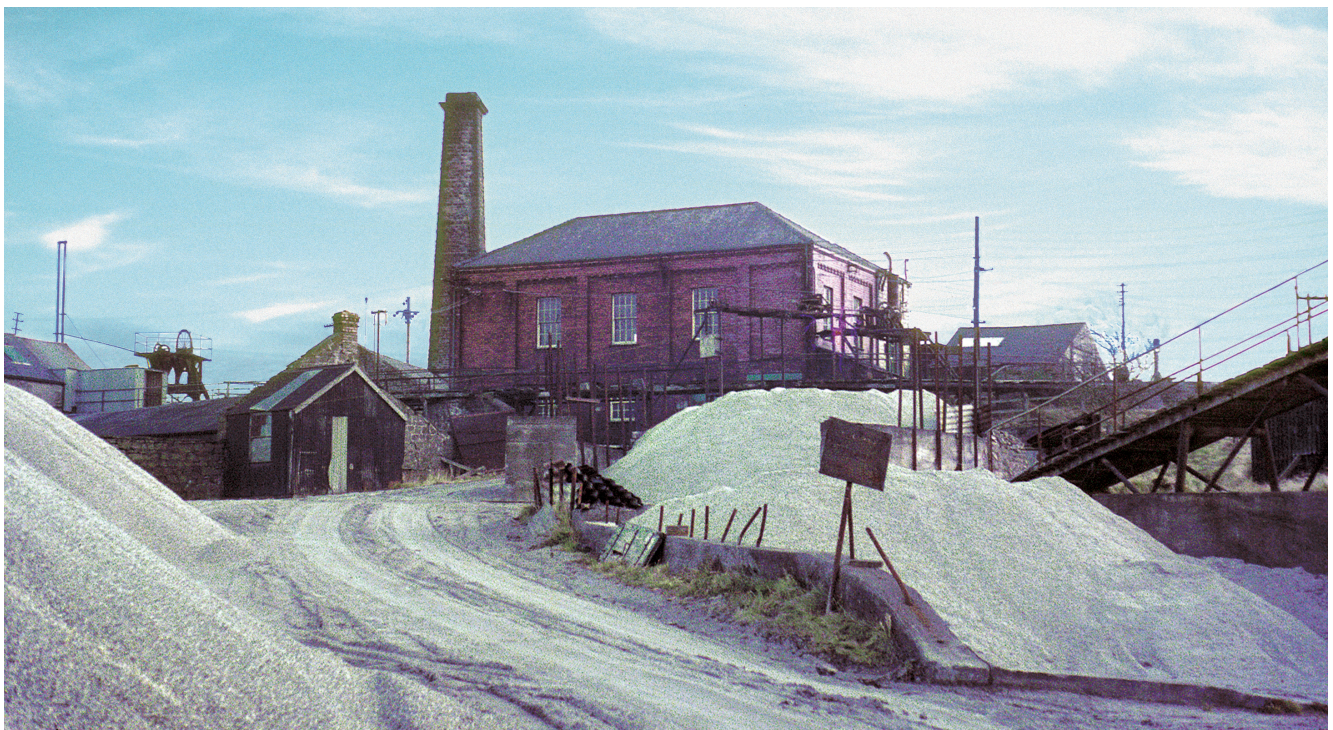
for recovery of significant material and associated recording of finds.

The spoil heaps associated with former coal mining are typically of modest size and are generally comparatively inconspicuous, but are in many cases the only present day expression of the former industry and provide valuable markers in tracing the position of coal seams.

A number of waste heaps associated with limestone and, to a lesser extent, sandstone quarrying contain weathered fossil material. Perhaps most significant are the large piles around Ridsdale and Bellingham containing the 'shell band' of the Redesdale Ironstone Shale, rejected as valueless by the ironstone miners.

In the south of the district, spoil heaps associated with the working of mineral veins at the Langley Barony, Stonecroft and Fallowfield mines remain. Most of the spoil heaps at the former Settlingstones Mine have been landscaped and although parts of the remaining coarse rock dumps are protected as an SSSI, for the mineralogical specimens they contain, they are becoming inconspicuous through increasing vegetation cover.

Stock piles of witherite at Settlingstones Mine in 1967



Building stone and the built heritage

Northumberland produces particularly high quality building stones. The majority of the county's active and historically known quarries are within the district under consideration. Stone forms an integral part of the landscape, present in field boundary walls, historic structures such as Hadrian's Wall and in the numerous stone houses, farmsteads and villages which provide as strong a sense of place as anywhere in the United Kingdom. The use of geological materials in the built environment eloquently demonstrates the inseparable links between natural and human landscapes. Understanding the properties and limitations of these materials provides important insights into the importance of the Earth's resources. Buildings may offer readily accessible opportunities to see a variety of rock types, and to appreciate ways in which the use of these materials has changed over past centuries.

Building stone in the district

Northumberland, as a whole, is a county characterised by sandstone buildings. However, a number of rock types in addition to sandstone have been utilized within the district.

Erratic boulders from superficial deposits such as till, glacial sand and gravel, or river deposits, have yielded small, but locally important, sources of building material. Many have been obtained as clearance stones from fields. They may comprise a variety of rock types. Carboniferous sandstones and limestones, and Whin Sill dolerite are most abundant, though greywacke sandstones and granitic rocks from south-west Scotland and a variety of volcanic rocks from the Lake District may also be conspicuous. Walls and buildings constructed from these stones can generally be recognised from the varied, and sometimes exotic, nature of the stones and commonly their rounded shape.

Around the Cheviot fringe there are examples of buildings utilising igneous rocks often with sandstone dressings: in Akeld the bastle, cottages and farm buildings, in Earle Parish Langlee and Langleeford farms, in Kilham Parish the forge and farm buildings and Thompson's Walls farm, and in Ingram Parish farm buildings including Hartside and Linhope. Some of these

are painted and may not be immediately obvious. Over the border in Scotland, Yetholm Church is built of the pitchstone-andesite from Thompson's Walls Quarry. Cheviot Volcanic rocks have also been used in field boundary walls, the more flaggy varieties of andesite have been quarried for local stone walling near Fairhaugh. Elsewhere, for example near Biddlestone, the well-jointed and thus easily worked trachyte dykes have been used. In the south of the district the old quarry cottages at the entrance to Barrasford Quarry are constructed principally from dolerite.

Although limestones are abundant within the district, they have not been employed as building stones, except in some drystone walls near outcrops. The main use of limestone in the built environment appears to have been as a source of lime for making mortar. Substantial quantities of mortar would have been required in the construction of Hadrian's Wall. As well as providing mortar for building, the use of lime on fields stimulated agricultural improvements, which in turn led to greater use of stone for new buildings, walls and roads.

Sandstone suitable for building is found throughout the Carboniferous succession of the district. Thickly bedded or massive fluvial sandstone provides the ideal material for building purposes; it has a siliceous composition making it durable and resistant to weathering, yet it can be freely worked. Almost every village and town throughout the district originally had its own quarry.

Barrasford cottages





Houses built from local sandstone in Front Street, Glanton

Sandstones from different geological formations and in different parts of the district often have subtle variations in composition, which impart a distinctive character to the stone and result in differences in building appearance from place to place.

For example, the contrasting colours of the rich iron-flecked brownish buff sandstones of the Bellingham area compared to the paler cream-coloured stone of Glanton, or the pinky red hematite-rich sandstone of the Wooler area. These variations contribute to the local distinctiveness of the landscape and the built heritage.

Some sandstones are notably coarser grained with a gritty texture, and in places were quarried for millstones as well as building stone. Abandoned partially completed millstones can be seen in Prudham Quarry.

Flagstone roofing stones once characterised some buildings. These were obtained locally from suitable thinly-bedded, mica-rich sandstone deposits wherever they were geologically available, but most notably in the south of the district, although typically as far north as Bellingham. For example, a small quarry in laminated flagstones [NY 881 785] provided roofing stone for the nearby village of Birtley. More prestigious buildings throughout the county used flagstone roofing where the cost of transportation could be afforded. However, many roofs were probably originally 'black thatched' using heather. These were replaced by Welsh slate during improvements in the 19th century. Today, the uniform purple Welsh slate is widespread, although several areas in north and mid-Northumberland display pantile roofs.

Abandoned millstones in Prudham Sandstone Quarry



History of use of building stone and development of the building stone quarry industry in the district

The earliest structures in the region used the most easily available local stone from field boulders and small extractions from nearby crags requiring minimal transportation. The first clear evidence for the quarrying and shaping of stone in the National Park comes in the form of the massive drystone walls of the Iron Age hill forts; andesite blocks were worked locally to form the ramparts of hill forts in the Cheviots. The most well-known is the massive hill fort on Yeavinger Bell where several ancient quarry faces can be seen in the interior of the fort.

In Roman times, Hadrian's Wall was built along a line of dolerite crags to provide natural defences. The hard 'whinstone' proved unsuitable for building as it could not be easily dressed, and was suitable mostly only for providing a rubble core for the wall. Sandstone was therefore worked in a series of quarries along the wall, for example at Queen's Crags near Housesteads. At Sewingshields [NY 810 699] the local sandstone is characterised by cross-bedding, and dressed stone in this section of the wall commonly displays such features. The sandstone was roughly dressed to provide coursed squared rubble to be used as a facing stone. The blocks were cut to a uniform size, particularly distinctive where the stone has been subsequently reused in later buildings. To a lesser extent, local limestone, clay and earth were also used in the construction of the wall.

Towers (also known as peles) and bastles, dating from the 13th to early 17th centuries, are a distinctive group of small, fortified structures common to the countryside of Northumberland and Scotland within about 20 miles of the border. Both types of building are typically constructed of large rubble blocks of irregular shape or roughly squared, sometimes arranged in rough courses. The stone types are locally sourced and generally directly reflect the local geology, and some examples incorporate stone from earlier Roman works. The gaps between stones are packed with stone chippings set in mortar containing little lime content. The walls are typically over a metre thick at the ground floor level, narrowing toward their tops. Good examples of such bastles can be seen at Akeld, Woodhouses near Holystone, Low Cleughs near



Hole Bastle, near Bellingham, constructed from random rubble sandstone with roughly dressed larger blocks used for corner stones and surrounds to openings. The flagstone roof is typical of those once common in southern parts of the district

Bellingham and pele towers at Elsdon and Tosson. The majority of rural buildings (farmhouses, cottages, steadings) date from the first half of 19th century, reflecting a period of agricultural improvement and rebuilding throughout Northumberland, and including several notable planned settlements such as Belsay, Chillingham, Ford and Cambo. It is from this time that many quarries of a more substantial size date, as well as the associated skills of quarrying and stone masonry. The development of towns such as Rothbury, Wooler and Bellingham from this time and throughout the later 19th century created an unprecedented demand for stone and large quarries were developed on the outskirts of the towns. Stone for Rothbury was obtained from local outcrops of the Fell Sandstone at Pondicherry. A quarry at Weetwood Bridge supplied a reddish purple siliceous sandstone for nearby Wooler and the surrounding area. The quarries at Longheughshields [NY 822 848] and Reenes [NY 826 843] provided stone for Bellingham.

It was the arrival of the railways in the mid 19th century which revolutionised the production of building stone in Northumberland. This enabled the transportation of stone over greater distances, and saw the development of larger scale quarries to supply the needs of urban development throughout northern England and in Central Scotland. The earliest railway, the Newcastle to Carlisle route, was built 1834-39, necessitating the

development of the Prudham sandstone quarry, which provided freestone for many railway structures such as bridges and stations, including Newcastle Central Station.

In 1847 the Newcastle to Berwick line began the process of opening up the northern part of the county, and a number of subsidiary lines enabled railway access into the centre of the county as the system was expanded through to the 1870s. Stone was initially used for the construction of the railway itself, and in places it was specified that for railway bridges all the stone should be ashlar, the highest quality freestone dressed so precisely that no joint should require more than one eighth of an inch of mortar. Soon stone was being sent north to Scotland, south to Newcastle and west to Carlisle. This resulted in an explosion of larger scale quarries in the second half of the 19th century. Many of these quarries employed the latest technology, with steam powered cranes to hoist stone onto small gauge mineral railways which transported stone to nearby railway sidings. The associated development of skills of quarrying, splitting, blasting, cutting and dressing put the region amongst the forefront of the industry in the UK.

Glanton Pike Sandstone Quarry, photographed in 1928



It was at this time that the major quarries such as those at Black Pasture, Blaxter, Cocklaw, Cragg, Deadwater, Doddington, Glanton Pike, Greenlaw, Gunnerton and West Woodburn supplied vast quantities of sandstone throughout northern England (including for stone architecture at Catcleugh Reservoir) and Central Scotland to satisfy the demands of urban growth and the expansion of cities such as Newcastle, Glasgow and Edinburgh. Records show that Prudham stone was used in Newcastle, Blaxter stone was sent to Edinburgh and Black Pasture stone was favoured in Glasgow.

Decline and survival

A nationwide shift from the use of natural building stone towards man-made materials occurred in the early 20th century. For example at Hethpool, cottages were constructed in the 'Arts and Crafts' style in a mixture of brick, stone and render. This shift, coupled with economic down-turns and the effects of two world wars, led to the closure of most of the building stone quarries by the mid 20th century. Some continued in production – albeit intermittently – and mostly those which were relatively mechanised, with a proven reputation of high quality stone and which already supplied a geographically large market. In the second half of the 20th century the majority of sandstone quarries had fallen into disuse, some becoming landfill sites for domestic refuse (e.g. Broomhill Quarry, West Woodburn), effectively sterilising any remaining resources. Others were landscaped or enclosed within agricultural land or plantations (e.g. Little Ryle, Millknock and Weetwood Bridge quarries), but most were simply abandoned. Many of the former building stone quarries are still visible today, and still contain resources of stone.

By the end of the 20th century the demand for stone showed a gradual recovery, partly due to the increasing requirement for repair of historic buildings throughout the United Kingdom. In addition, a demand for natural stone for new building within Conservation Districts and for townscape improvement schemes was supported by increasing recognition of stone as a prestigious material which 'adds value' to new properties.

Unlike some parts of the UK where all of the original stone quarries have closed, Northumberland is fortunate in having a number of surviving stone quarries where production continues today (e.g. Black Pasture, Blaxter, Darney, Doddington). This provides a continuous link



Blocks of sandstone stockpiled in Millknock Quarry awaiting processing

with the past which allows the use of stone which is 'in keeping' with the local character, as well as having similar physical and weathering properties, reducing the need for importing stone from other parts of the UK or abroad. In addition, a number of quarries have reopened in recent years, for example Millknock near Birtley, and Hazeldean and Brownieside quarries, just outside the district, north of Alnwick. These newly reopened quarries formerly supplied mostly local stone.

Others are relatively new operations or smaller quarries that have been significantly expanded in recent times. In the last few years two of these, Cop Crag and Blaxters High Nick quarries, have received planning permission to extend their workings, and most quarries are currently operating at higher levels of production than in the previous decades.

These active quarries supply stone for conservation and new-build throughout the country, but particularly in the north of England and Scotland. The operations today are relatively small-scale compared to the past, involving smaller quantities of stone. Most are owned by a limited number of national-scale companies and the stone tends to be removed as large unprocessed blocks and transported by road to central facilities for cutting and dressing. Modern planning constraints mean that these

quarries are much less environmentally intrusive than in the past. Compared to aggregate quarries, building stone quarries are typically much smaller scale operations, requiring less machinery and plant, and minimal blasting.

A rich legacy

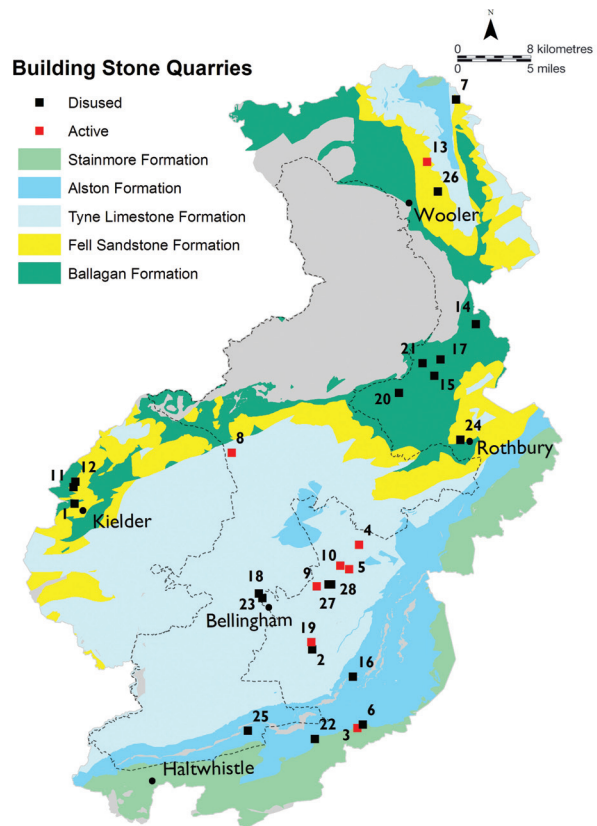
The presence of an historical stone quarrying industry has greatly contributed to Northumberland's unique landscape, not only the former quarries but also the richness of the stone built heritage, both rooted in the geology of the region. The quarries themselves represent the remains of a once thriving industry whose products have helped define the character of the county. Many of the abandoned sites now provide havens for wildlife, and sites of interest for the naturalist, archaeologist, geologist and in some cases for sporting activities such as rock climbing. Although some have been landfilled, and many used for small scale tipping, they can be viewed as a positive resource for the story of the past they tell, their part in defining the character of the region, the natural diversity they contain, and in some cases the potential stone resource still contained within them.

The working face at Cop Crag Quarry near Byrness showing the highly distinctive yellow-orange colour of the sandstone. The massive thick sandstone beds are split by inserting a series of parallel vertical drill holes and black powder blasting, visible on the quarry face in front of the figure



Building stones quarries table

Table of sandstone building stone quarries from Northumberland National Park and adjacent areas, giving location, current status and with a summary description of the stone type, quarry history and use of the stone. Examples of specific buildings are given for some quarries. Not all building stone quarries in the district are included, and most of those given represent larger scale commercial operations. Numerous smaller quarries once existed which supplied villages, farmsteads and individual buildings. The map shows that sandstone for building was obtained from a variety of geological formations throughout the district, exploited wherever suitable material was available.



Quarry name	Grid ref.	Status	Description
1 Bellsburn	NY 618 947	Closed, infilled	Active in late 19th century providing high quality sandstone. Probably taken by rail to Scotland.
2 Birtley	NY 881 786	Closed, partially infilled	A small quarry which provided sandstone 'slate' for roofing to Birtley and the local area. Many such quarries once existed throughout the region.
3 Black Pasture	NY 931 699	Active	One of the most important quarries in Northumberland with a long history of providing high quality freestone to cities such as Newcastle, Edinburgh and Glasgow, notably in the late 19th century. Today it operates on a much smaller scale, but large waste tips are still visible from the previous workings. Durham Cathedral; Mitchell Library, Glasgow; St Mary's Cathedral, Edinburgh. Repairs to Hexham Abbey.
4 Blaxter (Blaxters, Elsdon)	NY 933 902	Active	An important quarry supplying high quality sandstone which was much in demand for prestigious buildings in northern England and Scotland. Used commonly in Edinburgh, both for construction and more recently for repairs e.g. National Library of Scotland, Edinburgh (1937-55).
5 Blaxters High Nick	NY 922 875	Active	Creamy buff sandstone first extracted in the late 19th century. Quarrying ceased prior to the Second World War, but it was reopened in 1978 and has recently expanded. Currently used for buildings in Edinburgh, Newcastle and London.
6 Cocklaw	NY 937 703	Closed	Both limestone and sandstone were quarried, the sandstone mostly taken by rail to the Scottish Borders.
7 Collar Heugh	NU 040 395	Closed	One of several sandstone quarries in the Fell Sandstone of the Kyoie Hills area. Very thick beds of uniform cream-coloured sandstone, with several large faces preserving tool marks and drill holes for blasting, and used today for climbing. Probably mostly local use e.g. Haggerston Castle.

Quarry name	Grid ref.	Status	Description
8 Cop Crag (Copp Crag)	NT 792 004	Active	Distinctive, variable strongly coloured sandstone ranging from orange-buff to purple. Beds are typically up to 1-3 meters thick, some containing flakes of laminated silty mud with plant fragments up to c.50 cm long. Medical School, Glasgow. Rutland Building, Edinburgh. Used for repairs in Edinburgh New Town from 1970s.
9 Cragg Buff	NY 886 856	Active	Relatively small quarry last operated in early 20th century and reopened 1990. Buff yellow to cream, fine- to medium-grained sandstone. Transported by rail to Scotland, much used in Edinburgh.
10 Darney	NY 912 879	Active	An important quarry having supplied high quality fine grained pale freestone to cities such as Edinburgh in the first half of 20th century, production ceased by 1948. Subsequently reopened and recently expanded. Used commonly in Edinburgh, both for construction and more recently for repairs e.g. St Andrew's House (1936-9), High Court (1934-7), Usher Hall (1910-14), 45 George St (1974). Also used in Belfast.
11 Deadwater (Quirnal Quarry)	NY 617 966	Closed	One of several freestone quarries in the Fell Sandstone on the west of Deadwater Fell, which supplied large quantities of stone taken by railway to Scotland. Abandoned blocks and spoil heaps of orange-brown sandstone show large scale cross-bedding, with thinner interbeds of laminated sandstone.
12 Deadwater (Wirchet Quarry)	NY 618 973	Closed	A large group of small quarries which selectively exploited individual sandstone units. Stockpiles of roughly squared block remain, amongst numerous piles of waste from dressing operations. The sandstone contains orange ferruginous muddy flakes. Transported by rail to Scotland.
13 Doddington (Doddington Hill)	NU 008 326	Active	Distinctive pinkish sandstone quarried almost continuously since the late 19th century, with a reputation as being hard, compact and resistant to weathering. Much used in Scotland e.g. Royal Observatory (1892) and Reid Memorial Church (1929-33), both in Edinburgh. Also John Radcliffe Hospital, Oxford.
14 Glanton Pike	NU 062 146	Closed	Massive cross-bedded pale cream coloured sandstone, rather micaceous and fine-grained. The quarry closed by 1930. Used in Glasgow and Edinburgh.
15 Greenlaw Quarry	NU 015 089	Closed	Fine-grained uniform freestone with a pale yellowish-grey colour, spotted with white mica flakes on bedding planes. Active c. 1930. War Memorial, Alnwick; Lloyds Bank, Carlisle.
16 Gunnerton	NY 926 756	Closed	Produced high quality fine-grained cream coloured sandstone, initially for grindstones, then becoming a significant building stone quarry, closed in 1916. Used in Edinburgh e.g. tenements in Morningside and Meadows Pillars (1886).
17 Little Ryle	NU 024 107	Closed	Pale coloured, fine-grained, sandstone with variable orange banding and large clay clasts. Extensive areas of disturbed ground and spoil heaps with former working faces showing freestone units several metres thick overlain by thinly bedded sandstone. Vertical drill holes for blasting are preserved on the quarry face. Stone probably transported outside the district.
18 Longheughshields (aka Cragg)	NY 822 848	Closed	Extensive shallow workings exploiting sub-horizontal sandstone beds, leaving a large area of disturbed ground with a series of hollows separated by small spoil heaps. The sandstone varies from orange buff to pale cream in colour, with a gritty open texture. Extensive piles of undersized rubble remain. Supplied stone to Bellingham. Recorded buildings in Edinburgh include Jenners store (1893-5) and Old Waverley Hotel (1883-7).
19 Millknock (Mill Knock)	NY 880 794	Active	Strong orange buff coloured sandstone, with common mud clasts and carbonaceous fragments. The quarry closed by 1922, but was reopened in 2004 to supply the growing market in stone for restoration and new build mostly in Scotland. Provided stone for Birtley and Wark.
20 Whitelaw Plantation	NT 977 070	Closed, mostly infilled	Large quarry now enclosed in woodland, with vertical faces of thickly bedded creamy buff fine-grained sandstone in beds up to c.3m thick. Probably largely local use.

Building stones quarries table

Quarry name	Grid ref.	Status	Description
21 Blackchester Hill-Alnham	NU 003 102	Closed, mostly infilled	A number of small quarries in the Ballagan Formation and Fell Sandstone occur in the area south of Cheviot between Alnwick and Harbottle, particularly around Burradon and Netherton. These provided stone mostly for local use and most are infilled and incorporated into pastureland, although some still show original faces with spoil heaps.
22 Prudham (Prudhamstone)	NY 884 687	Closed	One of the most significant quarries in the region. Recorded as active from 1850, it closed in 1914. The quarry site today shows many remains of the former operations. Used for prestigious buildings throughout northern England and Scotland e.g. Newcastle Central Station; McEwan Hall in Edinburgh; Municipal Buildings in Stirling.
23 Reenes	NY 826 843	Closed, partially infilled	Former quarry in thick bedded units of fine grained uniform pale buff sandstone speckled with orange iron oxide and brown muddy patches. Provided stone for Bellingham.
24 Pondicherry Quarries (Cove and Pennystane)	NU 045 018	Closed	A group of large quarries which preserve massive vertical faces of thick-bedded, light buff, fine- to medium-grained sandstone with widely spaced joints. Some original tooling marks are preserved over parts of the faces, which are used today for climbing. Provided stone for Rothbury.
25 Sewingshields	NY 810 696	Closed	Sandstone characterised by cross-bedding which is commonly seen in dressed stone in the nearby Roman Wall.
26 Weetwood Bridge	NU 020 293	Closed, partially infilled	Significant quarry operating by the 1860s and much expanded by the end of the 19th century. The stone is medium- to coarse-grained-siliceous sandstone with a variable purple-red colour. Substantial spoil heaps and several large dressed blocks survive. Used locally in Wooler.
27 West Woodburn (Parkhead Quarry)	NY 899 858	Closed, mostly infilled	Medium-grained cream coloured sandstone with large muscovite flakes. Extensively quarried from the 1880s, but worked out by the 1920s. The quarry remains as a series of hollows separated by waste piles of undersized block linked by a central trackway. Used for East and West Woodburn, and in northern England and Scotland.
28 West Woodburn (Station or Broomhill Quarry)	NY 902 858	Closed, mostly infilled	Large quarry active from the 1880s. Now mostly landfilled, with a former trackway on one side preserving large stockpiled blocks, many several metres in size. Used for East and West Woodburn, and in northern England and Scotland.

The following four quarries are situated just outside the district, but are included owing to their importance in supplying stone.

Brownieside	NU 163 236	Active	Purple sandstone originally used locally and as far north as Berwick. Last worked at the end of the First World War, but recently reopened to supply stone for repairs mostly in Scotland.
Denwick	NU 209 145	Closed	Pale uniform buff sandstone favoured for carved and ornamental work. Used in North of England and Scotland e.g. Hancock Museum in Newcastle, Post Office in Sunderland.
Hazeldean	NU 154 204	Active	Pale coloured sandstone last worked at the end of the First World War, with limited extraction in the early 1930s. Recently reopened to supply stone for repairs, mostly in Scotland.
Ladycross	NY 952 549	Active	With a long history of production, this is one of the few remaining quarries supplying roofing slabs. The strongly coloured buff sandstone is still worked by hand, split along the thin bedding planes to provide 'stone slates'. Part of the quarry is now a nature reserve.

Opposite: Volcanic rocks exposed in the River Coquet near Shillmoor Farm

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Section 3

Exploring and celebrating geodiversity



Education and research

Geological literature and studies

The scientific study of the materials of the Earth's crust began in Europe towards the close of the eighteenth century. In Northumberland studies in the new science of 'geology' commenced early in the nineteenth century. In 1817 the naturalist John Winch published a paper *Observations on the geology of Northumberland and Durham* which discussed the Cheviot 'porphyrites', the early Carboniferous rocks of the Tweed valley, even the Roddam Dene Conglomerate. He also traced the Great Whin Sill from Bamburgh and the Farne Islands in the north, to the Roman Wall country in the south. Like many of the early observers, Winch was a naturalist whose interests ranged widely and who established links between geology and other sciences. His paper *Remarks on the distribution of the indigeneous plants of Northumberland and Durham, as connected with the geological structure of these counties* (1831) was extremely influential in the field of botany. In 1822 John Hodgson, noted local historian, included a systematic study of the quarries in the area of Hadrian's Wall with an account of the central sector, and in 1867 George Tate, postmaster in Alnwick, produced a geological appendix to the enlarged third edition of *The Roman Wall* by J H Collingwood Bruce. It was George Tate who established the main divisions of the Carboniferous in Northumberland.

Recognition of an intrusive igneous origin for the Whin Sills during the 19th century was based largely on studies within the present district, notably on sections exposed at Ward's Hill Quarry. Subsequently, the term sill became adopted by geological science for all sub-horizontal and, within stratified sequences, broadly concordant intrusive igneous bodies. Since then, many studies of the Whin Sills and their associated dykes have drawn upon evidence gathered from its exposures in Northumberland and much of the large volume of earth science literature derived from these studies has significance well beyond the district.

Much of our understanding of subsurface geology and regional geological evolution stems from the application of techniques and principles from other branches of earth science. Of these, perhaps the most significant are the disciplines of geophysics and geochemistry. Significant

advances in both the development of techniques in these disciplines, and the understanding of the regional geology of the United Kingdom have come from their application to geological problems within the district. Therefore, aspects of these disciplines can be considered an important facet of the district's geodiversity.

Geophysics

Geophysics is the study of the physical properties of geological materials and structures. The modern science embraces a very wide range of extremely sophisticated techniques derived from the principles of physics and designed to measure parameters of the Earth such as gravity variations, magnetic and acoustic properties, and natural radiation. The principle aim of these studies is to aid interpretation of the geometric form and nature of geological structures, often at considerable depths beneath the surface, and to aid understanding of the processes which may have created them.

Geophysical interpretation first made a significant impact on understanding the district's geology in the 1950s when a study of gravity anomaly data for the Northern Pennines and adjoining areas led to the postulation (subsequently proved), of the Weardale Granite and its role in the evolution of the Alston Block and adjoining Northumberland Trough. Following this seminal work, a variety of other geophysical techniques, including magnetic, seismic and magnetotelluric studies, have been applied to the investigation of the deep structure of the region.

Of particular significance have been a number of seismic profiling studies, in which the response of rocks to sound waves is used to image structures below the surface. Although detailed summaries of these investigations are not appropriate here, it is important to recall that these investigations have contributed greatly to our knowledge of the form and geological evolution of the Northumberland Trough.

The single most significant contribution from seismic survey techniques within the district is to our understanding of the Iapetus Suture (p. 18). In the early 1980s, geophysical seismic surveys were conducted across the suture, both onshore in Northumberland and offshore in the Irish Sea, in an attempt to define the geometry of the Suture at depth below northern England. The LISPB (Lithospheric Seismic Profile of Britain) passes



Vibrator vehicles operating in Northumberland during a seismic survey in the late 1980s. Large pads are lowered onto the road surface and a radio signal is sent which induces a vibration into the ground from each pad

through the district and images the Suture as a northerly dipping discontinuity in the rocks that passes right through the crust and close to, and possibly into, the underlying mantle. Similarly, in the mid 1980s electromagnetic techniques were used to image the structure of the Suture, and the combination of these results with those of the seismic survey has significantly increased our geological understanding of both the geometry of this structure and its effects on the subsequent geological evolution of the Alston Block and Northumberland Trough.

Seismic techniques have also been employed to investigate structures within the Carboniferous rocks of the Northumberland Trough which may have potential as hydrocarbon reservoirs (p. 83).

Regional magnetic anomalies, resulting from iron-rich basic rocks such as the dolerite of the Whin Sills and Palaeogene dykes, have contributed much to our understanding of these rocks at depth and to the inference of their presence beneath superficial deposits within the district. An unusual pattern of circular magnetic anomalies in the Ryal area, apparently related to the Whin Sills, may result from a circumstantial intersection of a number of linear anomalies, though the pattern is also consistent with its origin as a meteorite impact feature.

Similarly, regional gravity anomalies, resulting from the presence of the significantly less dense granitic pluton of

the Cheviot in the north of the district, and the significant differences in thickness of the sedimentary successions between the Northumberland Trough and Alston Block, have contributed greatly to research of the subsurface geology in both these areas.

Investigations of palaeomagnetism, recorded in the iron oxide minerals of the Whin Sills as they crystallised, have yielded evidence of the global position of the Whin Sill and therefore northern England at the time of its formation.

Geochemistry

Geochemistry is the study of the chemical composition of geological materials. It is an important tool for investigating the processes which have formed, and continue to influence, rocks and their by-products. A range of analytical and sampling techniques aid investigations into the distribution of chemical elements within the environment and therefore contribute towards our understanding of the geological evolution, of the dispersal of natural and manmade pollutants, and the geological development of economic resources. Modern techniques of isotopic geochemical analysis provide a range of methods for dating rocks, and processes that have affected rocks, and contribute significantly to our understanding of their geological evolution.

The distribution of a wide range of chemical elements in stream sediments and stream water across the district, as

determined by the British Geological Survey, is depicted in three geochemical atlases. As well as informing understanding of the local and regional geology, these provide valuable insights into patterns of man-made dispersion. Studies of stream water and sediment geochemistry from the Cheviot area have revealed a hitherto unrecognised zonation of the granite that has contributed much to the understanding of its geological evolution, and studies of metalliferous mineral concentrates within stream water from the area have detected previously unrecognised small-scale vein mineralization of copper, zinc, barium and lead.

Future earth science research potential in the district

Although much of the southern part of the district has been surveyed by BGS within the last forty years, there are significant areas farther north that have received very little systematic attention since shortly after the First World War. Selected areas have been the focus of academic study, but it is probably true to say that, in general, the district has not benefited from modern geological research. Consequently there is considerable potential to encourage and develop opportunities for earth science research and to extend the understanding of geodiversity in the district.

A number of research opportunities have been identified in the 'Wider Significance' sections earlier in the publication to which reference should be made – the list below merely highlights a few possibilities, in particular, the Quaternary landscape of the district is one that has increasing significance for the earth science community. It is recommended that a further study of possible topics should be conducted in conjunction with universities and other interested parties.

- There are few modern studies of the Cheviot igneous rocks; these rocks contribute to our wider understanding of this important phase of igneous activity in the evolution of the British Isles. The granitic rocks contain some pyroxene, a rare feature of rocks of this composition in Great Britain.
- The Cheviot massif appears to be very unusual in Britain. It is an upland area that has undergone glaciation during the Quaternary Period, but still preserves features relating to the action of longer

term, less physically dynamic processes. The preservation of these normally sensitive features in a landscape that has undergone glaciation is extremely unusual. Research into the ice-sheet evolution; diversion and dynamic of ice streams and cold-based ice preservation of summit forms, such as tors and weathered bedrock would enhance understanding on a national scale

- The Wooler-Cornhill area, with its extensive lake, fan and glaciofluvial deposits may provide significant opportunities for Earth Scientists to add vital pieces of information to our fragmentary record of the period during and immediately after the decline of the last great ice-sheet in Britain (e.g. long term palaeoenvironmental reconstruction from high resolution core sampling)
- The Hadrian's Wall district exhibits the classical landscape of a palaeo-ice-stream track, now recognised as being highly significant in the regulation of the mass balance of ice-sheet systems.

Geological and other societies

Geological societies perform an important role in communicating relevant knowledge and expertise both to their members and, in many instances, the wider public. The following geological societies and organisations are active within northern England and take an interest in the district:

- Cumberland Geological Society
- North East Geological Society
- Northumbria RIGS
- Natural History Society of Northumbria (Geology Section)
- Open University Geological Society
- Russell Society (Northern Branch)
- Yorkshire Geological Society

Although not a geological society, **the Haydon Bridge Nature Club** organises events which involve aspects of the district's geology and **Tarset Archive Group** are mapping geological features, associated buildings and quarries in their area.

All of these arrange programmes of lectures and field meetings and 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*. There is a future need to ensure the continued monitoring and review of the full range of varied geodiversity issues covered in this audit. Local geological societies may have a useful role in this process.

There is much that can be done to support opportunities outside the formal education curriculum, either through support for children's activities such as 'Rockwatch' clubs, or through an encouragement of evening courses and community-led study.

Archives and materials collections

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 geodiversity. In particular, such collections may include information on, or specimens from, locations or features which are no longer accessible and for which they now offer the only means of study and research.

The most significant geological archives relevant to the district are considered below:

Documentary sources

The British Geological Survey

As the national geological survey, BGS has an incomparable archive of information and materials collections relating to the district, dating back to the earliest years of geological mapping and research in northern England in the final quarter of the 19th century and continuing to the present day. 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.

Further information on BGS publications, data sources and information available from the British Geological Survey can be accessed on the BGS Web Home Page. www.bgs.ac.uk

Soil survey

Specialised information on soil character, properties and classification 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 the district is held by Natural England. Information on other geologically significant sites within the district is held by the Northumberland Wildlife Trust and Hancock Museum, Newcastle upon Tyne, which also has an extensive library of material relating to the geology of the district.

Beamish, The North of England Open Air Museum, Beamish, County Durham, holds documents relating to the rural and industrial history of northern England and has an extensive photographic collection including images of mining and quarrying.

Mine plans

Many years of mining for coal and vein minerals have produced a legacy of mine plans and related records. These documents, which contain huge amounts of often unique geological information, are an important element in the district's geodiversity. 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.

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

Many specimens of rocks, minerals and fossils collected within the district are held in the collections of Britain's national museums and university departments; important material is also held by BGS. These specimens, and their accompanying locality and other data, comprise an extremely important aspect of the district's geodiversity. Significant private collections of geological materials, mainly minerals, also exist.

The Natural History Museum, Department of Mineralogy, London collection includes mineral specimens from the mines of the Haydon Bridge area. Especially notable are specimens from Settlingstones and Fallowfield mines, including fine examples of witherite, alstonite, baryte, harmotome and niccolite. Specimens in the Russell Collection are of particular importance. The Tullie House Museum, Carlisle, and Killhope, The North of England Lead Mining Museum collections also include minerals from the Haydon Bridge area.

The geological collections of the following museums include fine minerals from Settlingstones and Fallowfield mines: National Museum of Wales, Cardiff; Hancock Museum, Newcastle upon Tyne; Hunterian Museum, University of Glasgow; Manchester University Museum; Oxford University Museum; Sedgwick Museum, University of Cambridge; Royal Museum of Scotland, Edinburgh; and Sunderland Museum and Art Gallery. The palaeontology collections of many of these museums include significant specimens from Northumberland.

The British Geological Survey Collections hold rock and fossil specimens taken from surface exposures and boreholes within the district. Thin sections of rocks from the district are registered in the BGS sliced rock collection.

Interpreting the geodiversity of Northumberland National Park and the surrounding area

The purpose of 'Interpretation' is to broaden visitors' and residents' awareness of the rich geological heritage in Northumberland National Park. Interpretation translates the technical language of the expert to the everyday language of all age groups. With that in mind,

interpretation should be creative and enjoyable.

Interpretation can be accomplished using a variety of media including on-site panels and signs, exhibits in a Visitor Centre, audio/visual productions, publications and events ranging from guided-walks to hands-on activities, living history re-enactments, and lectures. Geological interpretation embraces all methods of communicating earth science information to specialist and non-specialist audiences alike. Interpretation of the National Park's geological heritage should foster an appreciation of the area, and stewardship messages such as "tread lightly" on the natural environment can and should be interwoven.

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 district's ecology and archaeology. Thus, the understanding of, for example, a limestone grassland, a population of metallophyte plants, features visible on Hadrian's Wall, or the siting of a limekiln can be greatly enhanced if the geological factors responsible for these are explained in an appropriate context.

Delivery of earth heritage interpretation

The interpretive master plan

It is recommended that in the first instance an 'Interpretive Master Plan' for interpreting the National Park's geological heritage be produced. An Interpretive Master Plan provides ideas and an approach for communicating the stories that are associated with each geological site in a way where "the whole" becomes greater than "the sum of its parts". The whole story must be coordinated and take people on a journey of discovery throughout the National Park and surrounding areas.

To inspire a wider interest in the relevance of the geological heritage of the area, natural, scenic, historical, cultural, archaeological and recreational qualities need also to be woven into the interpretive themes for each site as well as key messages and related stories. The BGS/NNPA publication *Ancient Frontiers* produced in 2006 explored some aspects of the geology and landscape of the Hadrian's Wall area and has started the interpretation of the district. This has been welcomed locally and similar publications might be considered for other areas.

Sites and features to be considered for interpretation

The following sites and areas are recommended because of their potential to tell a story or stories relating to the geological heritage of the National Park and surrounding area. **The list does not imply any landowner agreement or support for siting interpretation material in any specific location, nor does it imply any right of access.** Wherever possible, routes should be selected to utilise Public Rights of Way and/or to cross Open Access land.

The sites are arranged in alphabetical order for ease of reference. Localities within Northumberland National Park are indicated with an asterisk.

Sites to be considered for 'on-site' interpretation

Akenshaw Burn and Lewis Burn, Kielder Forest [NY 622 892]

The sedimentary sequence exposed in the cliff face and visible from the trackside is worth interpreting as it is representative of much of the geology in the area and includes a series of fold structures. The track is already part of an existing marked cycle/horse route and the site could form part of a geological trail within Kielder forest. Liaison with the Forestry Commission is advised to make use of this resource.

Barrasford Quarry [NY 915 745]

Assuming agreement can be reached on the end-use of selected abandoned faces, appropriate interpretation could be erected adjacent to key features in the event of public access being possible (e.g. limestone raft in Whin Sill in upper part of quarry face). Liaison with the quarry operators is essential at this site.

Beltingham River Shingle [NY 786 642]

This site supports unusual metallophyte flora. Its relationship to mineral deposits and their former exploitation upstream could be interpreted in some way. A particularly fine opportunity exists here to reinforce the close relationship between earth science and ecology.

Barrow Scar [NT 900 061]*

The striking exposures of the Ballagan Formation seen in the river cliff from the Coquetdale road are excellent features to interpret. Close-up the strata contain many structures and fossils which can be used to explain how the bedrock informs us about the environment millions of years ago. This would be an ideal place for group-based interpretation. Located at the edge of the Cheviot massif, this would also be a good location to show the link between geology and the landscape, and as such could be part of any guided trail or information about the Upper Coquet valley.

Guided walk exploring the landscape above Walltown © NNPA



Black Pasture Quarry [NY 930 698]

This site exhibits fine exposures of ripple marks, which could be interpreted together with explanations of the quarrying and use of the stone from this site. Some restoration by appropriate vegetation clearance would be needed before this could take place. An opportunity also exists to comment on the vegetation that has developed over the abandoned workings and the link between the quarrying, geology and ecology.

Blakehope Nick [NY 713 983]

The lay-by located at the highest point on the Kielder 'Forest Drive' has interpretation boards describing the flora and fauna of the SSSI but nothing about geology. Adding information about the geology and the landscape on which the wildlife thrives would greatly add to the visitors' understanding of the area. The small quarry on the other side of the road in deeply weathered sandstone has revealed some large, well-preserved fossil plants. Geological interpretation could be incorporated into information given by the Forestry Commission about the Forest Drive either at this location or off-site.

Blindburn [NT 8307 1087]*

This location is ideal to explain some of the rocks and features visible within the Cheviot volcanic rocks and explore the processes that formed them. Andesite lava flows and pyroclastic breccia are visible at this site with a view point across stream; pull-offs are present. The site, within the Otterburn Training Area, could form part of a guided trail along the Upper Coquet valley.

Briarwood Banks [NY 797 640]

Existing on-site interpretation makes no reference to the spectacular gorge of the River Allen and its origins. The site offers a superb opportunity to make the connection between the Carboniferous rocks, glacial processes and the landscape we see today, including the woodland ecology and land-use.

Crag Lough/Steel Rigg [NY 752 675]*

Any review of the current interpretation panel and other information should explain the significance of ice and geology in forming the dramatic landscape seen here and how the builders of Hadrian's Wall have exploited it, in addition to interpretation of the Whin Sill itself.

Crindledykes Limekiln [NY 780 670]*

The restored limekilns are described in an existing panel,

though there is no interpretation of the limestone or the quarry which supplied it. More information about the nature and working of the key raw materials would provide a complete and integrated interpretation of this once important local industry.

Deadwater Quarries and Kilns [NY 604 969]

Located on the English-Scottish border are a number of geologically related features, including limestone and sandstone quarries, limekilns and old railway buildings. The importance of the geology in this area could be explained in various ways including a geological trail within Kielder Forest. Liaison with the Forestry Commission is suggested.

Doddington [NU 0080 3260]

One of the best panoramas of glacial features in the district can be seen from here, interpretation of the view to the east over Milfield Plain would enhance any visit to the district. Features include the River Glen which occupies a former glacial meltwater channel, a glaciofluvial fan complex and Milfield Plain, the site of a glacial lake.

Fallowfield Mine [NY 937 674]

This site is internationally important as the type locality for the very rare mineral alstonite as well as being of significance as a major Northumberland lead and witherite mine. Interpretation could include information about this economically important industry.

Fourstones [NY 887 678]

The recently re-erected winding wheel from Ellen Shaft of Settlingstones Mine deserves more interpretation. Witherite mining was a unique feature of Northumberland's extractive industry history and merits recognition and interpretation.

Glanton Pike Quarry [NU 062 146]

Interpretation describing the suitability of the sandstone as a building material, which was used throughout the village and exported to Scotland, could cover the quarry and the village. The panoramic views from the quarry could demonstrate clearly the links between the landscape and the underlying geology.

Greenchesters Quarry and Limekiln [NY 872 942]

Visible from the A68, these limekilns are in good condition and worthy of interpretation either at the site or off-site, for example at the car park where Percy's

Cross is located, or in locally provided literature. Apart from the usual social and agricultural information, the links between these man-made structures and the underlying geology could be highlighted drawing attention to the key raw materials and the adjacent limestone quarry which supplied it. This would provide an integrated interpretation of this once important local industry.

Haltwhistle Burn [NY 710 658 – NY 708 645]

Much information could be provided about this site to aid understanding of key geological, mining and quarrying features. It lends itself to geological interpretation, perhaps in a self-guided walks leaflet or within the Haltwhistle walking festival walks programme.

Harbottle Crags [NT 920 044]*

Information illustrating the links between geology, agriculture and the landscape could be provided, including how millstones were chiselled out of the sandstone. Consultation with the NWT and FC should take place regarding this interpretation and how geodiversity could be integrated into their information about the site.

Limestone Corner [NY 877 715]*

Evidence can be seen at this location of how attempts by Roman engineers to excavate the Vallum were thwarted by the hard nature of the stone of the Whin Sill. In addition, the site is an excellent viewpoint giving wide vistas across central Northumberland to the distant Cheviots and Border Hills. A fine opportunity exists here to interpret the foundations of this landscape.

Housesteads [NY 780 687]*

This site would be a good one to explain the significance of the dramatic landscape seen here and how the builders of Hadrian's Wall have exploited it. Attention could be drawn to the nature and use of stone in the monument, and interpretations of the stone buildings. In addition, landscape and land-use features encountered between the main car park and the Wall could also be explained. Liaison with the National Trust about interpreting the geology and landform of this and other sites along the Wall should be undertaken.

Makendon [NT 811 099]*

The base of the Cheviot volcanic sequence, which unconformably overlies deformed Silurian rocks here is

one of the most important boundaries in the geological history of Northumberland and is rarely visible in the district. Geological structures in Northumberland's oldest rocks are clearly visible in the river cliff from bridge over the River Coquet [NT 806 096]. Information should be provided in some form to explain these geological features, the formation of the landscape of the valley and links with the local flora. There are suitable pull-offs at several places. The site is within the Otterburn Training Area. This could be part of a guided trail along the Upper Coquet valley.

Milecastle 33 [NY 831 707]*

The view westward from here is one of the finest, easily accessible viewpoints in the Hadrian's Wall area. This is an excellent place to explain the nature of the highly distinctive scarp and dip landscape so characteristic of the area.

Parkhead Quarry, West Woodburn [NY 899 858]

Parkhead Quarry was worked for building material. The stone was used locally and exported to Newcastle by railway, and the quarry still contains many original features. It has potential for various methods of interpretation including boards or a short heritage and nature trail following the central trackway leading through the former sandstone excavations. Access is good as the site is adjacent to the A69 and a small area currently exists near the old quarry entrance which could be used for parking.

Pondicherry [NU 045 018]

At a site already popular for woodland walks, more information could be provided about the quarry face describing how the sandstone has been used as a building material throughout much of Rothbury, and linking geology to the economic and social history of the area. Other interpretation about this site could be included in information about Rothbury itself.

Redesdale Ironstone Quarry [NY 887 842]

This is one of the best fossil localities in the district. This, combined with its historical economic importance, makes it an ideal site for interpretation. Interpretation of the varied geology exposed in the quarry face and associated fallen blocks with descriptions of how and why ironstone was worked here would greatly increase the experience. This would be a good place for group visits.

Rothley Crags [NZ 043 886]

This location, popular for walking and climbing, would benefit from interpretation of the glacial overflow channel, the crags, and the folly made of local cross-bedded sandstones.

Settlingstones Mine [NY 849 687]

The site of this world famous and unique witherite mine deserves interpretation.

Simonside Hills and Lordenshaws [NZ 024 987]*

Interpretation illustrating the links between geology and archaeology, geology and the landscape and geology and flora of the area should be produced for this site. This may be most appropriate in Rothbury and in off-site literature as the area is a popular destination but a relatively wild upland area.

Thirlwall Castle [NY 659 662]*

Information about the castle and the use of stone has general and educational interest and should be included in interpretation about the site.

Tipalt Burn [NY 659 661 to NY 687 683]*

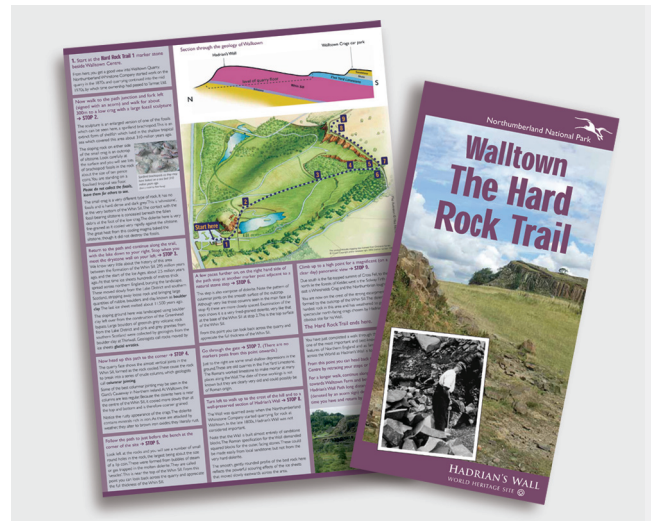
An exposure of the 'reef-like' Low Tipalt Limestone is located on Open Access land [NY 6799 6795] and has considerable potential for inclusion in various interpretation mediums and walks. It must be emphasised that this is not a locality from which fossils can be collected, but is an excellent example of where fossils can be observed *in situ*.

Tossen Quarry and Limekilns [NU 027 010]*

The restored limekilns are described in two existing panels, although there is no interpretation of the limestone or the quarry which supplied it. The nature and working of the key raw materials should be considered when the panels are renewed to provide a complete and integrated interpretation of this once important industry.

Vindolanda [NY 771 663]*

Some comment on the sourcing and use of local building materials in the Roman structures would enhance the interpretation of this site, as would an explanation of the varied use of geological materials in the archaeological remains.



Walltown Quarry and Walltown Crags [NY 668 658]

More detailed geological interpretation could augment the existing 'Hard Rock Trail'. In addition, the site is an excellent viewpoint giving wide vistas across central Northumberland to the distant Cheviots and Border hills. From above the quarry [NY 6753 6639], the view north across Thirlwall Common, reveals streamlined features of the Tyne Gap Ice Stream. Interpretation to explain these features could help visitors appreciate how the landscape in the southern part of the district has been modified by ice and the links with glacial processes, the underlying hardrock geology, and flora of the area.

Whitelee Bridge [NT 715 049]*

From the lay-by on the A68 the links between the geology and the landscape in the Upper Redesdale valley can be seen. This includes Northumberland's oldest rocks visible in the road cutting opposite, the intrusion in Lumsdon Law which was worked economically, the siting of Catcleugh Reservoir, the limestone workings on the remote fells to the south and the sandstone quarry at Echo Crags. Many of these features could be incorporated into a geological trail. This could be integrated with information about the nearby NWT Whitelee Reserve and local accommodation providers in the area.

The following places at the southern margin of the district were highlighted for interpretation in the North Pennines AONB Geodiversity Audit and Action Plan:

Cupola Bridge [NY 800 591], Langley Chimney [NY 840 610] and Stublick Colliery [NY 833 604].

Suggestions for non site-specific areas to be interpreted

As above, no specific styles of interpretation are suggested for the areas described below, but the information may be suitable for guided trails, walks and inclusion in literature about the localities.

Colt Crag and Throckrington area

Information could be devised for this area to include landscape interpretation and use of materials such as whinstone and limestone.

Cragside

Although there is already much information written about Cragside, more information could be provided linking the geology to the landscape of the area and the building stone used for the house, which came from a number of known quarries within the grounds.

Gunnerton and Swinburne area

This locality is a good one to explore and view 'Whin Sill country' including views of Barrasford Quarry.

Hadrian's Wall Footpath and Cycle Trail*

The area's principal long distance trail offers an obvious and ideal opportunity to incorporate interpretation of geological and landscape features which are crossed by, or visible from, the route. Attention could also be directed towards the nature and use of stone in the Wall. Interpretation could be delivered in a number of ways, for example as a component of a guide booklet or leaflet to the entire route, or the route could be treated as a number of carefully selected component sections. This should be investigated as interpretation is developed for the area.

Haltwhistle Burn

The attractive and popular footpath through this valley is an ideal location from which to explain the geology and former extractive industries, together with their collective impact upon the ecology and present land-use. Any route could be extended to include the area around Cawfields Quarry.

Haltwhistle Town

Even in a small town like Haltwhistle, the varied use of geological materials, and the impact and constraints of natural landscape features has much of interest to offer both visitors and residents alike including substantial educational value for local schools.

Harbottle Castle, Harbottle Crags and the Drake Stone*

Information about the area around the castle and crags could explore the links between geology and landscape, geology and the built heritage, and working of the sandstone for millstones.

Harthope Burn to Housey Crag and Hedgehope Hill*

Information about this area could include localities to explore the granite, andesites, metamorphic aureole and tors, and investigate links between the geology and flora on the Cheviot massif. Peat formation and Quaternary habitat development could also be included in the area of Broad Moss below Hedgehope.

Kielder Forest Drive

This scenic drive crosses areas of Northumberland which have few visitors. Visits could be enhanced by providing information about the formation of the landscape in this area and how materials were exploited in the past.

Nether Hindhope to Gaisty Law

Information for a walk between these two locations could include visits to Silurian basement rocks, volcanics, and descriptions of the topography related to lava flows, deep-weathering of volcanics and perched Quaternary gravels.

Otterburn to Cottonshope Range Road*

Although cutting through the MOD training area this road is often open to the public and would make an excellent geological trail. A whole variety of geological features can be explored within tens of metres of the road between Cottonshopeburnfoot and Alwinton.

Pennine Way*

Proposals to interpret the geological and landscape features of the Pennine Way have been made in the Geodiversity Audit and Action Plan for the adjoining North Pennines AONB (NPAONB). Collaboration between NNPA and NPAONB could be a useful means of delivering appropriate interpretation of the route through the Hadrian's Wall area and on through Redesdale and the Cheviots. Any other future information about the route should be encouraged to include much more about the geology and landforms.

Settlingstones and Stonecroft

The mining features remaining from the lead, zinc and witherite mining industries of this area would be interesting to interpret. Such a walk offers excellent

opportunities to explain the interdependence of ecology with geology, for example by highlighting metallophyte plant communities. Further afield, aspects of the formerly important sandstone quarrying industry at Prudhamstone could also be incorporated.

Simonburn

This area is a good one to illustrate the interdependence of geology, ecology and land-use. Access and facilities are available in Simonburn village.

Simonside and Lordenshaws*

Information focussing on the geology of the area and its link to the archaeological remains could be provided for a route using the existing network of footpaths and Open Access land.

Thorngrafton Common

The varied landscape and land-use in the immediate vicinity could be interpreted including explanations of aspects of the excellent distant views available from the area.

Upper Redesdale valley*

Information could be developed for this area taking in the varied geology of the valley, including the riverbank exposures of Northumberland's oldest (Silurian) rocks,

The Lordenshaw rock, a panel of rock art cut into the Fell Sandstone; looking north-west towards the Cheviots

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the sandstone quarry with sedimentary structures at Echo Crag, the igneous intrusion with columnar jointing worked at Lumsdon Law; the latter two have great views across Catcleugh Reservoir. The geological and geographical reasons for the siting of the dam could be explored together with the surviving workers' hut.

Wall, Fallowfield and Acomb

This area could be used to demonstrate landscape, use of rocks and local lead, barium and coal mining. There are plenty of existing public footpaths that could be utilised.

Wooler/Cornhill Quaternary Deposits

Information about the formation, deposits and potential records of the proglacial lakes in this area could be provided.

General landscape around the National Park

Views of the landscape could be interpreted including description of views seen within, and from edges of, the Park e.g. from the A697 and the different geology seen at local villages, such as Powburn, Wooler and Longhorsely.

General Quaternary landforms of the Cheviots*

Interpretation linking various Quaternary features found within and around the Cheviots could be produced. This would explore the effect of the underlying bedrock geology on the ice-streams, the glacial processes which would have been active in the area, the resulting landforms and how various aspects of this modified landscape have been exploited by humans and plants.

Geology and landscape seen around Kielder

The geology at Plashetts and Kielder Column, the geology of sculptures and railway bridges, Kielder Castle and Border Mires could all be included in interpretation, including via the Kielder boat trips.

Geology of the Alwinton-Byrness Road

Potential for interpretation of Barrow Scar, Cheviot lavas, Silurian basement rocks and landslides.

Langley and Stublick

These two sites, at the southern margin of the district, were at the southern margin of the district were highlighted for interpretation in the North Pennines AONB Audit and Action Plan.

District wide geological interpretation

These are some basic themes and ideas that could be explored when developing the Interpretive Master Plan for the National Park and surrounding area.

Building stones

Northumberland is uniquely characterised by its sandstone built heritage, with a continuity of stone quarrying from pre-Roman times to the present day. The geodiversity is directly reflected in the diversity of building materials used historically throughout the district. More information should be made available to illustrate the variety of stone buildings in the district and explore the links between geology, our built heritage and our industrial heritage (i.e. quarrying industry).

Rocks and rock climbing

Numerous crags and former quarries have spectacular vertical rock faces and are well-known to local rock climbers. Liaison with local climbing groups and clubs should take place to produce geological and ecological information or guides for climbers to well-visited climbing sites. This would help climbers appreciate what rocks and features their finger and toes are gripping onto and why some are more fragile than others.

Drystone walls

Drystone walls are found throughout the district and have an intimate relationship with the underlying geology. Information could be made available to help explain the variety of stone types and construction styles, explore how the style is dependant on the rock type which limits its geographical extent and describe different features (and their purpose) that are observed in some walls.

Eminent geologists and naturalists in Northumberland

Information about the story of geological investigation in the district should be made available. This could include details from the early days, when Victorian 'gentleman geologists' explored, described, painted and interpreted the area to more recent times where even with the help of modern technology we still don't know all the answers!

Geology and archaeology

More should be made to illustrate the links between the geology and archaeology of the district. This could explore how the geology underlying the landscape and the availability of various geological materials has influenced the development of human settlement and exploitation of the environment through the ages.

Geology and flora

Observing geology and flora in tandem is interesting and informative. Links between the bedrock geology, the shape of the landscape and the plants that thrive in various areas could enhance any visit in the district. This should be explored in the National Park Biodiversity Action Plan review and incorporated into various interpretation products for the area.

Geology and landscape of the Cheviots

Following the success of the Hadrian's Wall book, '*Ancient Frontiers*', material exploring the geology and landscape of the Cheviot massif could be produced to help interpret the dramatic scenery in the northern part of the district. This would provide an understanding of the evolution of the Devonian Cheviot volcanoes and their influence on the development of the Northumberland Trough, on Quaternary events and landscape evolution. This has the potential to be as successful as the Hadrian's Wall book because of the overwhelming popular interest in volcanoes and ice.

Iconic views of the National Park

Through its varied geology, the district displays a varied landscape. More could be done to interpret the best views in the district with information or diagrams explaining why the landscape is shaped the way it is. This could be aimed at visitors and local people. Many locals will know the landscape visible around them and interpretation can help them to imagine what lies beneath that landscape and what has created the views they know so well.

Limekilns

Dozens of historic limekilns are scattered throughout the district. Some kilns have been restored, others are ruinous. It may be useful to collate information about the function of kilns, the raw materials used (and where they were sourced), and the different architectural styles. This could be augmented with pictures showing the variety of attractive kilns throughout the district.

Links with similar geological areas

Making links or even 'twinning' with another place in the world which has modern day equivalents to the districts Devonian volcanoes, Quaternary ice-streams or Carboniferous environments could be instructive as well as positive for tourism providers.

Millstones

Following on from some research already carried out on millstone quarries in Northumberland, information exploring the links between geology and our cultural heritage, and industrial and agricultural past could be made available. For example the rock types appropriate for millstones, quarries in which suitable stone was found, how millstones were extracted and where they can still be seen (e.g. Harbottle, Prudham).

Northumberland landscape for younger audiences

Information aimed at encouraging the younger generation to look at the scenery and buildings they pass whilst travelling through the district could be produced. Features that could be used include: stone-built castles and towers, meandering rivers, dry-stone walls, limekilns, lakes, rocky escarpments and quarries. There are lots of potential mediums for this including photos or images of a range of geologically-related features that could be spotted and 'ticked-off'. This should include some additional information about the features for a more in-depth educational product to use with school or other visiting groups. This approach could be applied equally to any geological walks and trails at specific sites.

Northumberland's landscapes and textures

Images of different landscapes and geological features visible in Northumberland could be collated to explain the links between geology, Earth processes, ecology, archaeology and our social and economic heritage. These images could be augmented with close-up pictures of rocks showing appropriate colours and textures for the location. For example, a picture of the Simonside landscape with a close up image of cross-bedding, ripple features or attractive oxidation fronts in sandstone; for the Whin Sills, a detail of vesicles or columnar jointing, or a microscope image.

Northumberland passport

To encourage people to visit new places, a number of geological sites could be chosen across the district with a linking theme (e.g. 'useful' rocks, rocky features, or 'rocks and art') and as each one is visited the passport holder would collect a unique 'stamp' in their passport from a local amenity (this could be, for example, a stamp from the local shop or a brass rubbing placed at the site). Once all the sites have been visited the passport holder would collect a NNP badge or certificate. This idea could also be devised to create a journey through time, 'the

geological story unfolding', by visiting different ages of rock across the district and recording in their passport something appropriate to rocks of that age.

Northumberland's rocks and fossils

Information about the variety of rocks, fossils and structures visible in the geology of Northumberland could be provided. This could include where to see them, how to recognise them and what they tell us about the district's geological history.

Patterns and markings in the Fell Sandstone

The Fell Sandstone which often underlies the characteristic escarpments and crags seen within the north of the district usually forms flat topped surfaces in relatively soft rock which are ideal for carving. This is where most of Northumberland's cup and ring marks are found, but it is also a rock unit which weathers to form natural pits, hollows and depressions. More information could be produced exploring the links between geology and the natural and man-made patterns/textures observed in the rock and adding a different angle to a subject which already has many publications.

The value of our rocks

The wide range of extractive industries in the district, both past and present, link geology to industrial and cultural development of the region and deserve interpretation. This could include interpretive information on a wide range of resources and products including coal, ironstone, limestone, building stones, clay roof tiles, millstones, sand and gravel and water.

The opening into the pot at Great Tosson Limekiln



Opposite: Old quarry in the Whin Sill at Walltown Crags

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Section 4

Geodiversity Action Plan



Introduction

This Plan sets out actions for geodiversity in Northumberland National Park. It does not claim to be conclusive, but rather aims to be a stimulus for action. It is hoped that the plan will evolve as more people and organisations become involved in the process. The Action Plan is designed to be revised and updated.

The plan includes suggestions for lead partners to take forward each of the actions, but this is in no way intended to be exclusive. Interested groups and individuals are encouraged to get in touch if they would like to be involved or have ideas for actions.

The actions with the highest priority have been indicated with an asterisk.

Action plan

Objective	Action	Key organisations	Date	Priority
1. Contact and organise local interest in geology	1.1 Encourage the involvement of the Northumbria RIGS group in conserving and developing geodiversity in the district	RIGS, NWT, BGS, NNPA, interested individuals	2007	*
	1.2 Continue to identify partners, including companies and local groups who are interested in geology; keep an up-to-date database of contacts	All	2007 onwards	*
2. Designate and maintain data on important geological sites	2.1 Review procedures for designating geological sites and establish geodiversity steering group for NNP	NNPA, NWT, RIGS, BGS	2007 onwards	
	2.2 Revise SNCI sites using agreed criteria	NWT, RIGS, BGS,	2008	
	2.3 Identify sites as suitable RIGS sites and designate	RIGS, NWT, BGS, NNPA	2008 onwards	*
	2.4 Give information to site owners	RIGS, NNPA	Ongoing	
	2.5 Manage site data, incorporate in GIS and pass to Districts, County Councils, NWT etc.	BGS, NNPA, NE	Ongoing	*
3. Monitor condition of sites	3.1 Monitor the condition of geological SSSIs and ensure that all have a management plan or statement	NE	Ongoing	*
	3.2 Monitor the condition of other important sites	RIGS, BGS, NNPA,	Ongoing	
	3.3 Maintain a database of sites with condition	NE, NNPA, BGS	Ongoing	
	3.4 Work with local users and owners of sites to monitor condition, e.g. climbers	Local interest groups	Ongoing	
4. Ensure protection of sites through local and regional policies and strategies	4.1 Ensure that policies protecting geodiversity are included in the Local Development Framework and National Park Management Plan	NNPA	2007	*

Objective	Action	Key organisations	Date	Priority
4. Ensure protection of sites through local and regional policies and strategies	4.2 Ensure that important sites are included on the LDF proposals map	NNPA	2007	*
	4.3 Consider making the Geodiversity Audit Supplementary Planning Guidance	NNPA	2008	
	4.4 Lobby to ensure that other district and regional plans include policies to protect geodiversity	NNPA, BGS, NWT, RIGS	Ongoing	
	4.5 Ensure that geodiversity is used as a base for the NNPA Landscape Character Assessment	NNPA, BGS	2007	*
	4.6 Ensure that geodiversity is incorporated into the NNPA Landscape Strategy	NNPA	2007	*
	4.7 Take geodiversity into account in Development Control decisions	NNPA, DCs	2007 onwards	*
	4.8 Ensure that geodiversity is included in the Otterburn Training Area ILMP review	NNPA, BGS, MoD	2009	
5. Practical conservation	5.1 Identify and prioritise sites in need of practical management.	BGS, NE, NNPA, RIGS	2007/08	*
	5.2 Identify groups to carry out the work	NNPA, NWT, NE	Ongoing	
	5.3 Ensure that protection and enhancement of important geological and geomorphological features and related historic features are included in Agri-environment schemes e.g. limekilns, quarries, tufa outcrops	NE, NNPA, Agents	2007 onwards	
	5.4 Consider deforesting crags within FC plantations during Forest Design Plan reviews	FC, NNPA	Each plan review	
6. Geodiversity of active quarries	6.1 Encourage Quarry Operators to prepare quarry specific Geodiversity Action Plans	NNPA, BGS, Quarry Operators	2007 onwards	
	6.2 Seek opportunities to report, record, conserve and enhance geodiversity in active quarries	NNPA, BGS, Quarry Operators, RIGS	2007 onwards	
7. Local use of stone	7.1 Establish which quarries were, and are, key to creating local character and distinctiveness.	NNPA, BGS, EH, Quarry Operators, Architects, Local history groups	2009	
	7.2 Investigate re-opening of small quarries (craft quarries) to provide locally distinctive stone for specific building projects	Quarry companies, architects, BGS, NNPA	Ongoing	

Action Plan

Objective	Action	Key organisations	Date	Priority
7. Local use of stone	7.3 Ensure that local planning policies allow for this small scale quarrying	NNPA, NCC, DCs	Next review	
	7.4 Consider including more information in the NNPA Building Design Guide review to encourage awareness and use of local materials for repair and new-build	NNPA, BGS, EH	Next review	
8. Interpretation and public awareness	8.1 Commission a Geodiversity Interpretive Master Plan to provide ideas and approach for communicating themes at appropriate sites using a variety of media, incorporating proposals in 8.2 to 8.10 below	NNPA, BGS	2007/08	*
	8.2 Investigate the possibility of producing a book, or map and guide, on the geology of the Cheviots. Look into funding options and links with the Cheviot Hills Project	NNPA, BGS, Borders Council	2008	*
	8.3 Ensure that geodiversity and landscape are key elements of any further development at Once Brewed Visitor Centre	NNPA	Ongoing	*
	8.4 Develop more interest in geotourism – e.g. investigate European INTERREG project. Link to North Pennines AONB initiative and Scottish Borders. May include leaflets for self-guided walks and cycle trails	NNPA, NPAP, BGS	Ongoing	*
	8.5 Encourage guided walks and events especially linking to current events such as Berwick and Haltwhistle Walking Festivals	Programme providers, NNPA, BGS, RIGS	2007 onwards	
	8.6 Investigate opportunities for promoting geodiversity within the Otterburn Training Area	NNPA, MoD, BGS	2007 onwards	
	8.7 Hold workshops in central and northern areas of the National Park highlighting importance of these areas and how people can get involved	NNPA, BGS	2007/08	*
	8.8 Investigate setting up 'Rockwatch' or other events for younger children outside formal education	RIGS, NWT, NNPA	2008/09	
	8.9 Approach groups with related interests e.g. local history, natural history and archaeology	NNPA, BGS	Ongoing	
	8.10 Ensure that a comprehensive amount of information is available on web sites including details of sites with public access	NNPA, BGS, NWT, RIGS	2007 onwards	*

Objective	Action	Key organisations	Date	Priority
9. Education and training	9.1 Encourage formal education opportunities, by providing information for local schools and suggesting suitable site visits. Facilitate these visits and study where possible	NNPA, BGS, RIGS, Schools	Ongoing	
	9.2 Provide information for Higher Education courses (Open University and local universities). Produce a guide for courses and study indicating good sites in the district to view and study features	NNPA, BGS, OUGS	2008	
	9.3 Provide training for builders and architects to encourage use of local stone	BGS, NNPA	2008/09	
	9.4 Provide training for NNP staff on geodiversity in each of the NNP areas	BGS	2007	
	9.5 Train local guides e.g. tourist providers	BGS, NNPA	2008	
	9.6 Provide training for local groups carrying out conservation work on sites	BGS, NE, RIGS	2008	
10. Research	10.1 Work with universities to identify suitable research topics within the area e.g. aspects of the Cheviot Granite and Quaternary studies	NNPA, BGS, Universities	2008/09	
	10.2 Identify all the items within the archaeological research agenda that link to geodiversity e.g. provenance of axe stones, millstones, locations of quarries	NNPA, BGS	2007	
	10.3 Identify any research topics investigating biological and geological links e.g. whin specific lichens	NNPA, Universities, NE, BGS	2008	
11. Funding	11.1 Investigate future funds for each of the actions above	All	Ongoing	*

Abbreviations used in the key organisations column of the action plan:

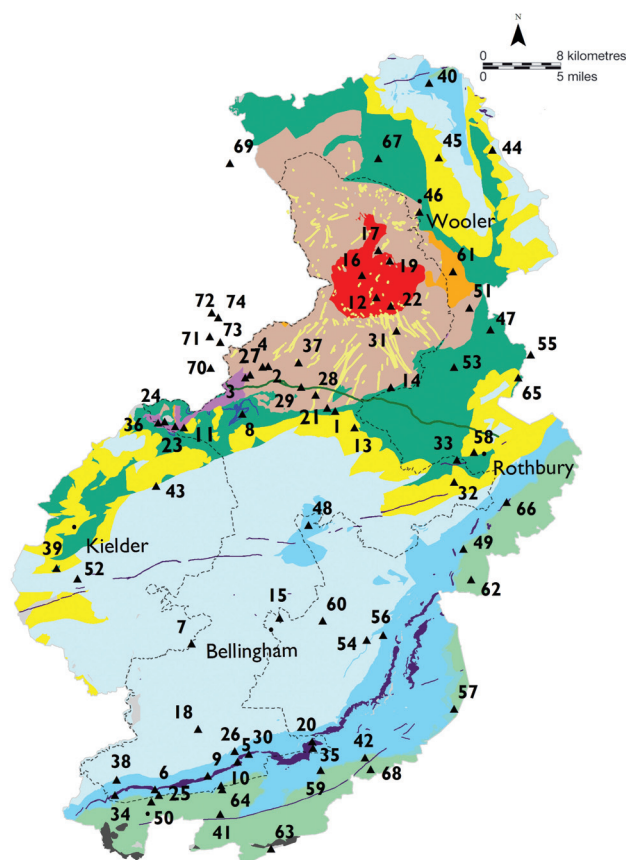
BGS	British Geological Survey
DCs	District Councils
EH	English Heritage
FC	Forestry Commission
MoD	Ministry of Defence, Otterburn Training Area
NCC	Northumberland County Council
NE	Natural England
NNPA	Northumberland National Park Authority
NPAP	North Pennines Area of Outstanding Natural Beauty Partnership
NWT	Northumberland Wildlife Trust
OUGS	Open University Geological Society
RIGS	Regionally Important Geomorphological and Geological Sites groups

Geodiversity sites in Northumberland National Park and the surrounding area

A number of Geodiversity sites have been identified as part of this study. They have been selected as representative examples of particular geological features in the context of Northumberland National Park and surrounding area. They do not replace, but stand alongside, SNCIs, SSSIs and other designated sites.

It is recommended that this site list should form the basis for undertaking actions 2 to 6 in the preceding Northumberland National Park Geodiversity Action Plan. It is anticipated that the list will be revised during implementation of the Action Plan.

Many of these sites are also considered appropriate for interpretation and are discussed earlier in this publication (Pages 105 to 112).



Geodiversity sites

Geodiversity site	Geological feature	Condition	Status
Sites within Northumberland National Park			
1 Barrow Scar [NT 900 061]	River banks and cliffs exposing sandstone, mudstone and limestone sequence	Stable, partly overgrown	SNCI, SSSI and MoD training area
2 Blindburn [NT 830 108]	River bank and stream bed exposures display lava flow over irregular surface of lapilli-tuff	Stable	SNCI, SSSI and MoD training area
3 Bridge over R Coquet , NE of Makendon [NT 806 096]	River banks and hillside outcrops expose folded and steeply dipping shales	Stable	SSSI and MoD training area
4 Buckham's Bridge [NT 824 107]	Abandoned roadside quarry displays flow-banding and flow-jointing in andesite	Stable	SSSI, Access Land and MoD training area
5 Busy Gap [NY 798 695]	Hillside with natural rock outcrops of Whin Sill, metamorphic rocks and geological structures	Stable	SSSI and Access Land
6 Cawfields Quarry [NY 712 666]	Abandoned Whin Sill quarry, also exposes sedimentary rocks and geological structures	Stable, face becoming obscured by vegetation	SNCI
7 Chirdon Burn [NY 750 818]	Natural exposures of sedimentary rocks in stream bank and cliffs	Unknown	SNCI and Access Land

	Geodiversity site	Geological feature	Condition	Status
8	Cottonshope Head Quarry [NY 750 818]	Abandoned roadside quarry exposes basaltic lavas and underlying/overlying sediments	Stable but degraded	SSSI, SNCI and MoD training area
9	Crag Lough [NY 767 680]	Lough formed by fast ice flow during glaciation	Stable	SSSI
10	Crindledykes West Quarry [NY781 670]	Abandoned Great Limestone quarry and limekiln	Stable	Some areas are Access Land
11	Echo Crag [NT 742 044]	Natural sandstone escarpment on hillside displaying sedimentary structures with small abandoned quarry	Stable	SNCI and Access Land
12	Great Standrop [NT 943 180]	Tor formed of granitic rock	Stable	SSSI and Access Land
13	Harbottle Crag [NT 920 044]	Hillside crags of sandstone with abandoned millstone quarry	Stable	NWT reserve
14	Harden Quarry [NT 958 086]	Working aggregates quarry in minor intrusion associated with Cheviot granite	Active quarry faces change regularly	SSSI, NWT reserve and Access Land
15	Hareshaw Burn [NY 842 844 to NY 842 846]	River banks and cliffs display sedimentary sequence, remains of ironstone workings, Hareshaw Linn waterfall	Stable, some areas overgrown	Active quarry
16	Harthope Burn [NT 927 202]	River banks and cliffs display contact between two different types of granitic rock	Stable	SSSI
17	Hawsen Burn [NT 940 230 to NT 950 228]	River banks and cliffs display granophyric granite, dykes cutting andesite and saproplitic granite. Fault rock, quartz veins and breccia also exposed	Stable, naturally vegetated in parts, some minor landslips	SSSI and Access Land
18	Henshaw Common [NY 757 729]	Thick peat deposits in large elongate grooves, which potentially have a long (> 15 000 year) environmental record	Stable, but surface disturbed by forestry operations	SSSI and Access Land
19	Housey Crag [NT 957 218]	Tor formed of hornfels	Stable	Access Land
20	Limestone Corner [NY 876 716]	Whin Sill partially excavated from Vallum of Hadrian's Wall	Stable	SSSI and Access Land
21	Linbriggs [NT 891 064]	Roadside and river cliffs expose features associated with lava flows and flow breccias	Stable, some river cliff areas may be subject to rockfalls	SAM
22	Linhope Spout [NT 958 171]	Waterfall and surrounding outcrops display granitic rock (quartz-monzonite)	Stable	MoD training area
23	Lower Ramshope Burn [NT 733 045]	River banks reveal steeply dipping shales showing sedimentary structures and fossils	Stable	SNCI and Access Land
24	Lumsdon Law [NT 722 050]	Abandoned quarry in porphyritic basalt displays igneous structures and good views over the Upper Rede valley	Stable	Access Land

Geodiversity sites

Geodiversity site	Geological feature	Condition	Status
25 Milecastle Inn [NY 716 660]	Abandoned limestone quarries in Four Fathom Limestone	Stable	SNCI and Access Land
26 Queen's Crags [NY 795 706]	Hillside with crags of sandstone and small abandoned (some Roman) quarries	Stable	SNCI
27 River Coquet , 3/4km WSW of Fulhope [NT 811 099]	Hillside outcrops showing unconformity between steeply dipping mudstones and overlying volcanoclastic breccia, at base of Cheviot Volcanics	Stable	SSSI and Access Land
28 River Coquet , SE of Kateshaw Crag [NT 879 078]	Riverbank exposures showing intrusive feldspar porphyry dyke, one of a radial swarm	Stable	SSSI and Access Land MOD Training Area
29 River Coquet , E of Dumbhope Law [NT 864 086]	River outcrops of the Acklington Dyke	Stable	SSSI and Access Land MOD Training Area
30 Sewingshields Crags [NY 810 703]	Hillside rock outcrops of the Whin Sill and a meltwater channel	Stable, bedrock is poorly exposed	SNCI, SSSI and MoD training area
31 Shank Burn [NT 964 145]	Large meltwater channel	Stable	SSSI
32 Simonside Hills and Lordenshaws [NZ 024 987]	Hillside sandstone outcrops with archaeological interest	Stable	Access Land
33 Tosson Quarry and Limekiln [NU 027 010]	Abandoned limestone quarry and limekiln, which has been restored as tourist attraction	Stable, quarry is degraded,	SSSI and Access Land (Simonside Hills only)
34 Walltown Quarry [NY 670 660]	Abandoned Whin Sill quarry with nature trails Sedimentary rocks above sill also exposed	Stable, saplings obscure part of face	SNCI
35 Walwick Fell [NY 877 709]	Limestone grassland with small abandoned limestone quarries	Unknown	Private land
36 Whitelee Bridge and Lumsdon Burn [NT 715 049]	Road cutting and stream bank sections formerly exposed steeply dipping shales and breccia	Stable, road section is very degraded and overgrown	SNCI and NWT reserve
37 Windyhaugh [NT 715 049]	River bank exposures of flow-brecciated andesite with laminated internal sediment	Stable	SNCI, SSSI and MoD training area
38 Tipalt Burn [NY 659 661 - NY 687 683]	Stream section with river banks displaying sedimentary sequence including fossils	Stable	SSSI and Access Land (north part)

Sites within district, but outside Northumberland National Park

39 Akenshaw Burn [NY 609 897]	Stream bank section through mudstone and cementstone sequence	Stable, subject to some river erosion	SNCI and Access Land
40 Barmoor Mill Quarry [NT 998 404]	Old quarry face exposing the Eelwell Limestone	Stable	SNCI
41 Beltingham Shingles [NY 780 640]	Riverside shingle banks rich in minerals and of ecological importance	Stable	SSSI and NWT reserve

Geodiversity site	Geological feature	Condition	Status
42 Black Pasture Quarry [NY 931 699]	Abandoned sandstone quarry, adjacent to periodically active quarry, reveals shelly horizons in the sandstone and good sedimentary structures	Stable but seriously overgrown in old quarry	NWT reserve and active quarry
43 Blakehope Nick Quarry [NY 713 983]	Disused sandstone/sand quarry along Kielder Forest Drive; fossil plant pieces and mineralised fractures exposed in deeply weathered sandstone	Stable	SSSI and Access Land
44 Dancing Green Hill [NU 064 334]	Natural sandstone escarpment on open moor displays sedimentary structures	Stable	Access Land
45 Doddington Quarry [NU 008 326]	Abandoned sandstone quarry, adjacent to periodically active quarry	Stable. Changing exposures in working quarry	Active quarry and Access Land
46 Earl Quarry [NT 988 269]	Inactive quarry exposes extrusive volcanic andesites	Stable, periodic working may occur	SNCI
47 Glanton Pike Quarry [NU 062 146]	Abandoned sandstone quarry, displaying sedimentary features	Stable, partly overgrown and some rubbish tipped	Private Land
48 Greenchesters Quarry [NY 875 943] and Limekiln [NY 875 943]	Abandoned Oxford Limestone quarry and limekiln	Stable, quarry is very degraded	SNCI
49 Greenleighton Quarry [NZ 034 917]	Abandoned quarry in Great Limestone	Stable	SSSI
50 Haltwhistle Burn [NY 714 659 – NY 708 648]	Stream section with river cliffs displaying sedimentary sequence	Stable	SNCI
51 Ingram valley [NU 040 169]	Cobble gravel alluvial terraces in valley floor	Relatively stable except in flood events	SNCI and SSSI
52 Lewis Burn [NY 631 886]	River bank sections alongside good cycle track displaying sedimentary sequence with fossils and structures; small abandoned quarry	Stable, some areas overgrown, river too big to cross	SNCI and Access Land
53 Little Ryle Quarry [NU 024 107]	Abandoned sandstone quarry with views to the Cheviot Hills	Stable, partly overgrown	Private Land
54 Long Craggs [NY 933 822]	Natural sandstone escarpment on hillside displaying sedimentary structures	Stable	Access Land
55 Low Broomepark [NU 104 120]	Road cutting through thick sedimentary sequence with moderate dip	Stable, but now very degraded adjacent to fairly busy public road	SNCI
56 Lunga Craggs [NU 104 120]	Natural sandstone escarpment displaying sedimentary structures	Stable	Access Land
57 Mootlaw Quarry [NZ 024 750]	Working aggregates quarry in Great Limestone displays good geological structures	Quarry face sections change over time	Active quarry
58 Pondicherry [NU 045 018]	Disused quarries with large sandstone faces	Stable	Adjacent to footpath

Geodiversity sites

Geodiversity site	Geological feature	Condition	Status
59 Prudhamstone Quarries [NY 885 686]	Abandoned sandstone and limestone quarries with high faces displaying sedimentary sequence; old millstones lying around	Stable, but becoming overgrown High faces	SNCI
60 Redesdale Ironstone Quarry [NY 887 842]	Abandoned ironstone quarry with fossiliferous limestone and mudstone units	Stable	SNCI
61 Roddam Dene Bedrock Landforms [NU 023 207] [NU 036 207]	River bank and cliff exposures of sandstone and conglomerates; access is difficult. Ice-contact deposits and landforms (kames, deltaic sediments, etc)	Bedrock stable; section in ice-contact deposits is being eroded	SNCI and SSSI
62 Rothley Crag [NZ 042 885]	Natural sandstone crags on hillside displaying sedimentary structures and sandstone folly	Stable	Access Land
63 Stublick Colliery [NY 833 604]	Former colliery buildings	Stable	SAM
64 Thorngrafton Common [NY 782 666]	Hillside with natural outcrops of sandstone	Stable	Access Land
65 Thrunton Quarry [NU 091 096]	Brick clay quarry exposes pro-glacial laminated lake clays	Stable	Active quarry
66 Wards Hill Quarry [NZ 079 966]	Abandoned quarry, Whin Sill intruded into Great Limestone	Stable	Private Land, adjacent to road
67 Woodbridge Quarry [NT 945 325]	Sand and gravel quarry exposes glacio-fluvial deltaic sediments and periglacial features	Stable	Active quarry
68 Written Crag [NY 937 687]	Natural crags and abandoned Roman sandstone quarries	Unknown	Private Land

Sites on the Cheviot massif outside district

69 South of Coldstream [NT 790 320]	Streamlined glacial deposits and bedrock, e.g. drumlins	Stable	Scotland
70 Nether Hindhope [NT 790 320]	Disused quarry exposing steeply dipping shales	Stable	Scotland
71 Hangingshaw Hill and Quarry [NT 769 139] and [NT 765 142]	Hillside displays meltwater channel cutting through weathered bedrock. Disused quarry in deeply weathered andesite	Stable	Scotland
72 Kippie Knowe Quarry [NT 778 159]	Disused quarry exposes saprolitic deposit in pyroclastic breccia	Stable	Scotland
73 Stanshiel Hill [NT 780 133]	Solifluction deposits on hillside – talus, head	Stable	Scotland
74 Swanlaws Quarry [NT 771 164]	Inactive quarry exposing saprolitic deposits developed in flow-banded andesite	Stable, periodic working may occur	Scotland

Glossary

This glossary aims to provide simple explanations of some of the geological terms used in this publication. The explanations are not intended to be comprehensive definitions, but concentrate instead on the way in which the terms are used in this book.

A

Algae Large group of simple photosynthetic plants with unicellular organs of reproduction

Alluvial Pertaining to the action of rivers and floods

Ammonoids A subclass of molluscs, typically characterised by a coiled, chambered shell, with distinctive lines (sutures) between the chamber walls and the outer walls of the shell

Amygdale A gas bubble cavity in an igneous rock that has been infilled later with minerals

Andesite A fine-grained igneous rock of intermediate composition, typically containing phenocrysts of feldspar and pyroxene

Anticline A convex upwards fold with the oldest rocks in the centre

Armour-stone Large stone block used in coastal defence and other engineering works

Aureole Zone surrounding an igneous intrusion in which the rocks have been affected by heat from the intrusion, typically metamorphosing the rock to hornfels

B

Basalt A fine-grained, dark igneous rock composed of calcic plagioclase and pyroxene, may also contain olivine

Bedding Layering in sedimentary rocks parallel to the original surface of deposition (true bedding) or inclined to it (false, current or cross bedding)

Bivalve A class of molluscs with paired shell valves (eg mussels)

Brachiopods Solitary marine shelled invertebrates, the shell is made of two unequal valves

Breccia A rock composed of angular fragments greater than 2 mm in diameter

Bryozoans Small aquatic colonial animals

C

Calcareous Containing calcium carbonate

Cementstone A name used to describe a limestone, usually containing clays, that is, or was, used to make cement

Chronostratigraphy The standard hierarchical definition of geological time units

Clast A fragment in a pyroclastic or sedimentary rock

Cleavage Splitting, or the tendency to split, along parallel closely positioned planes in a rock

Conodonts An extinct group of marine animals whose most commonly preserved parts are microscopic elements, made of mainly calcium phosphate, some of which superficially resemble small fish teeth and worm jaws

Crinoids Marine animals (sea lillies) composed of calcareous plates

Cross-bedding Layers in a sedimentary rock inclined to bedding and related to the original direction of current flow

D

Drumlin A low, rounded hill of glacial till, which was moulded into a streamlined shape by glacier ice passing over it

Dyke A sheet of igneous rock emplaced along a steep, generally vertical fracture, normally discordant to the structure of host rocks

E

Era The largest division of geological time, divided into Periods

Extrusive Describes igneous rocks that have been extruded onto the Earth's surface, rather than being intruded beneath the surface (intrusive)

F

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 and calcium

Freestone Any fine-grained sandstone or limestone that can be sawn easily

G

Gastropods Molluscs belonging to the class Gastropoda, usually with coiled shells (eg snails)

Geomorphology The study of landforms and the processes that form them

Goniatites An extinct group of ammonoids useful in determining time zones within sequences of rocks

Graptolite A group of extinct colonial marine organisms. They consist of one or more branches or stipes in which individuals in the colony occur in rows

Greywacke A sandstone containing a high proportion of silt, clay and rock fragments in addition to quartz grains

H

Hornfels A hard fine-grained metamorphic rock adjacent to an igneous intrusion, that has been partly or completely recrystallised by the heat from the intrusion

Hydrothermal Processes involving the reaction of hot groundwaters with pre-existing rocks, resulting in changes in the mineralogy and chemistry of the rocks, the formation of mineral veins and replacive 'flat' deposits

I

Igneous rock A rock that has formed from the cooling of magma (molten rock)

Inlier An outcrop of older rock surrounded by rocks of younger age

J

Joint A fracture, or potential fracture, in a rock along which there has been no displacement

L

Lapilli-tuff A pyroclastic rock in which 25-75% of the clasts are between 2 mm and 64 mm in diameter

Limestone Sedimentary rock composed mostly of calcium carbonate

Lithology The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents

Lithostratigraphical The determination of the stratigraphical relationship of rocks based on their lithology

M

Magnetic anomaly The value of the local magnetic field remaining after the subtraction of the dipole portion of the Earth's field

Metamorphism The process of change in the mineralogy and structure of a rock as a result of the effects of heat and/or pressure

Monocline A steep flexure of rocks on either side of which the strata are horizontal or dip at only low angles

Monograptid A graptolite with a single stipe

O

Orogeny An episode in Earth history that produced crustal thickening following the collision of tectonic plates and resulting from magmatism, folding thrusting and accretion, leading to regional uplift and mountain building

Ostracod A group small arthropods with a twin shell

Outlier A remnant of a younger rock surrounded by older strata

P

Palaeomagnetic Describing the remnant magnetic characteristics frozen in a rock during its formation and reflecting the direction of the Earth's magnetic field at that time

Pegmatitic Textural description of an area within an igneous rock that is notably more coarsely crystalline than the surrounding rock

Periglacial A zone or environment peripheral to glaciers, so that it is very cold but not covered by ice-sheets

Phenocryst A crystal in an igneous rock, usually of near perfect shape, that is larger than that in the groundmass

Plagioclase A very common group of rock-forming feldspar minerals

Porphyritic Describing igneous rocks in which larger crystals (phenocrysts), are set in a finer grained or glassy groundmass

Pseudomorph A mineral or aggregate of minerals that have replaced a pre-existing mineral, and having retained the original mineral's shape

Pyroclastic Describes rocks that form directly by explosive ejection from a volcano

Pyroxene A group of magnesium, iron and calcium silicate minerals

R

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

S

Saprolite A soft, decomposed rock, formed in place by chemical weathering. It is characterised by its retention of some of the structures that were present in the rock from which it was derived

Seatearth The fossil soil underlying a coal seam

Sedimentary Describes rocks formed by the accumulation of fragments from the wasting of previous rocks or organic materials, deposited as layers of sediment

Siliceous Rich in silica (SiO₂)

Stratigraphy The definition and description of the stratified rocks of the Earth's crust

Syncline A concave-upwards fold with the youngest rocks in the centre

T

Throw The amount of vertical movement on a fault

Tor A mass of rock rising above the surrounding landscape with free faces on all sides; originally used in south-west England for distinctive residual masses of rock, mostly granitic, capping hills

Trachyte A fine-grained igneous rock of intermediate composition, typically containing phenocrysts of feldspar and mica

Tufa A porous or cellular deposit of calcium carbonate deposited from lime-rich springs

Tuff A pyroclastic rock composed of clasts with an average grain size less than 2 mm

Turbidity current A dense, turbulent sub-marine flow of mixed water and sediment, capable of very rapid movement

U

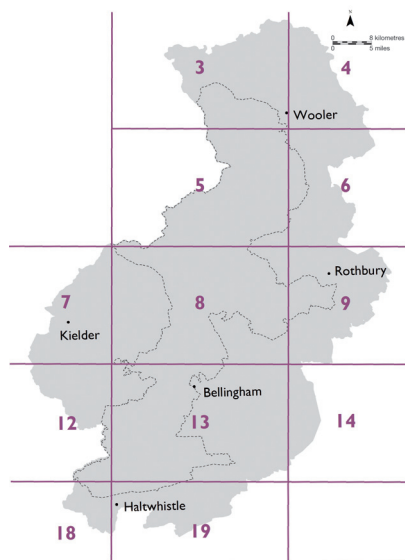
Unconformity A substantial break in the succession of rocks following a period of erosion or non deposition

V

Volcaniclastic Describes a rock containing clasts derived from volcanic activity

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**British
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NATURAL ENVIRONMENT RESEARCH COUNCIL

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