Northumberland Coast
Area of Outstanding Natural Beauty
and European Marine Site

GEODIVERSITY AUDIT AND ACTION PLAN


BERWICK
UPON-TWEED
ALNWICK
Coquet Island

CONTENTS

The Northumberland Coast at Longhoughton Steel

Summary

This Geodiversity Audit and Action Plan focuses on the Northumberland Coast Area of Outstanding Natural Beauty (AONB) and European Marine Site (EMS). It is a companion document to the AONB/EMS Joint Management Plan.

The area covered by this plan is shown on the map on the inside front cover of this document.

This document comprises an **Audit** and an **Action Plan**:

The **Audit** summarises the geological and geomorphological heritage of the area and identifies:

- the different rock types;
- the importance of the rock types or particular sites in terms of biodiversity and their impact on the landscape;
- the uses of the rocks; and
- any wider significance of each rock type.

The **Action Plan** is arranged under the headings:

- Understanding more about our geodiversity (addressing the need for continued research and study);
- Conserving our geodiversity (addressing designations and site-based conservation work);
- Interpreting our geodiversity (addressing how people might be guided towards greater enjoyment and understanding of the coast's geological heritage); and
- Education and lifelong learning about our geodiversity (addressing how programmes of formal and information education might be developed).

It is the intention that interpretation and education projects may be integrated with other subjects and themes along the coast.

Accompanying this document is a GIS-based digital dataset containing all of the sites and features referred to in this plan, accompanied by spatial information, basic descriptions and further references.

Howick Bay, excavated in Carboniferous sandstones, limestones and shales

INTRODUCTION

Areas of Outstanding Natural Beauty (AONBs)

AONBs were created by the National Parks and Access to the Countryside Act (1949) and since 1956 forty AONBs have been designated in England and Wales. The UK's AONBs and National Parks are within a worldwide category of protected areas known as International Union for the Conservation of Nature (IUCN) Catgeory V Protected Landscapes, designated so that their qualities can be enjoyed by present and future generations. AONBs range in size from the Isles of Scilly (16 km^2) to the Cotswolds (2038 km^2). The other Protected Landscapes in the North East region are the North Pennines AONB and Northumberland National Park. AONBs and National Parks have the same protection in the landuse planning system.

The Northumberland Coast AONB was designated in 1958 and covers an area of 138 km^2 along 64 km of coastline from Berwick to the Coquet estuary. Though nowhere more than 2.5 km wide, this area is remarkably rich in natural and cultural heritage.

European Marine Sites (EMS)

In 1994 the UK Government incorporated into law as the Conservation (Natural Habitats, &c.) Regulations 1994, the EU Habitats Directive and the Birds Directive. This is commonly known as the Habitats Regulations. A European Marine Site is any area designated under the Habitats Regulations as Special Protection Area of Special Area of Conservation that includes a marine area.

The EMS covers 115 km of coastline over 635 km^2 of shore and sea, from Fast Castle Head to Alnmouth and includes the Farne Islands and Lindisfarne.

The Northumberland Coast AONB/EMS has long, sweeping beaches, rocky cliffs and isolated islands. The bird and marine life of the coast is internationally important. It also has a 7,000 year history of human activity and its castles, fishing villages and Christian heritage all contribute to its special character.

More detail on the purpose of designation and the special qualities of the AONB can be found in the AONB/EMS joint management plan.

The AONB/EMS Management Plan

Through the AONB/EMS Management Plan, policies for the better conservation, enhancement and understanding of wildlife, cultural and historical assets are already in place. Included in the management plan is an objective to produce and implement the findings of a geodiversity audit and action plan. The production of this document and the implementation of its action plan may be seen as a fundamental objective of the AONB and EMS Partnerships over the next five years. AONB/EMS Management Plan Policy N13 and actions N13.1, N13.2, N13.3 and EN8.7 recommend the production of this Audit and Action Plan and the implementation of actions arising out of it.

The Purpose of this Geodiversity Audit and Action Plan

The principal aim of this plan is to guide the conservation and interpretation of the geological features of the Northumberland Coast. It is also intended to support the development of sustainable nature-based tourism in the area.

The main objectives of this Geodiversity Audit and Action Plan can be summarised as:

- to improve knowledge and understanding of the geodiversity resources on the Coast;
- to identify the main geological formations and features and to evaluate their contribution to local geodiversity;
- to identify linkages between the area's geodiversity and its landscape character, biodiversity, economic and cultural history;
- to identify threats to geological features and opportunities for their conservation and enhancement; and
- to identify a network of individual sites which encapsulate the essential features of the area's geology and where possible identify how these might be used to support interpretation and education programmes and projects.

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 area's Earth heritage. In this plan the key elements of the area's geology are outlined in sufficient detail to inform and underpin specific recommendations and action points.

The principal audience for this document is not practising geologists, but those who manage and influence the Northumberland Coast AONB and EMS. Readers of this document who may have little geological knowledge, or be unfamiliar with the geology of the area, should be able to appreciate the geology of the Coast, why it is important and how it might be conserved, interpreted and used to support educational programmes.

Geodiversity – what is it and why does it matter?

Recent years have seen many different definitions of Geodiversity put forward, but it is succinctly captured in Mick Stanley's 2001 definition: 'The variety of geological environments, phenomena and processes that make those landscapes, rocks, minerals, fossils and soils which provide the framework for life on Earth'. Geodiversity makes the links between people, landscape, biodiversity and culture and is one of an area's chief natural resources. It has a profound influence on the landscape, habitats and species and also on the economic activities and history of settlement in any given place.

Following the UK government's ratification of the UN Convention on Biological Diversity, which resulted from the Rio Earth Summit in 1992, and the production in 1995 of the UK Biodiversity Steering Group's Report "Meeting the Rio Challenge", the concept of 'biodiversity' is now widely understood. Subsequent years saw the preparation and implementation of Biodiversity Action Plans for most parts of the UK, including Northumberland. Biodiversity is now accepted as an essential element in sustainable planning and management strategies. Until recently the parallel concept of geodiversity has attracted little interest, despite its fundamental importance in underpinning biodiversity. However, the last five years in particular have seen a growing interest in the concept of geodiversity and in the production of geodiversity audits and action plans. The North East of England, (notably the North Pennines AONB Partnership through the production of the area's first GAP and establishment of the European Geopark, and Natural England which has helped to champion geodiversity policies in strategic documents), has been at the forefront of embracing geodiversity and making it part of mainstream conservation thinking and practice.

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

Geology is fundamental to almost every aspect of life. Geological resources provide the raw materials for civilisation, be they fuels, water supply, metal ores or bulk and industrial minerals and building materials. A clear understanding of geology is vital to the design and siting of buildings, roads, railways and airports as well as to the safe control of waste disposal and the management of a wide range of natural and man-made natural hazards. The importance of the range and diversity of Earth science features – the 'geodiversity' – of any area is as important a facet of its natural heritage as its wildlife interests.

Conservation, sustainable management, educational use and interpretation of geodiversity is thus as important as that of biodiversity, archaeology etc. Knowledge of an area's geology undoubtedly makes it much easier to understand the character of the local landscape, and also makes it easier to understand an area's biodiversity. Geodiversity literally and figuratively underpins all aspects of heritage.

Designated Sites and Features

International, European and National Designations

The varied landscape of the Northumberland Coast includes a wealth of sites and features which, for a variety of reasons, are subject to conservation designations of various kinds. These include international designation (RAMSAR sites), areas of Europe-wide conservation importance (Special Protection Areas (SPA) and Special Areas of Conservation (SAC)), and national designations (National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSI)).

Geological Conservation Review 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 geological heritage. GCR sites are those of national or international importance which have either been notified as SSSIs or are being considered for such notification. Publication of descriptions of GCR sites is being undertaken in a series of 42 thematic volumes. Since 1991, publication of descriptions of GCR sites has been undertaken by the Joint Nature Conservation Committee on behalf of the three country agencies, Natural England, Scottish Natural Heritage, and the Countryside Council for Wales.

Local Sites

Other localities have non-statutory designation, for example, as County Wildlife Sites or the Voluntary Marine Nature Reserve at St Abbs Head. There is no active Regionally Important Geological and Geomorphological Sites (RIGS) network in Northumberland and no sites are currently recorded under this second tier designation, which has the same status as the County Wildlife Sites (Local Sites). A review of Local Sites and the criteria for their designation was being proposed at the time of writing this document.

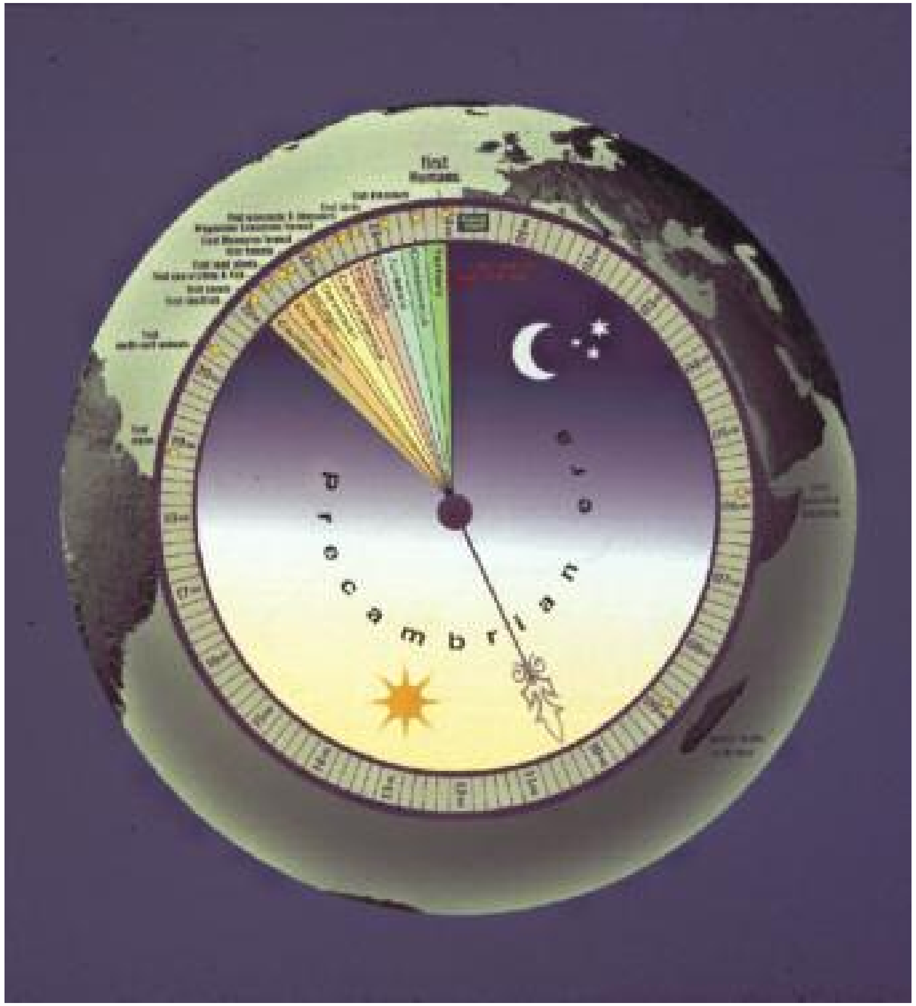
A complete database of designations, sites, area, their principal interest feature and their geological interest has been complied for this Geodiversity Audit and Action Plan and is available on the AONB/EMS Partnerships' websites.

Geological Time

The rocks of the Northumberland coast provide us with a tangible record of long past events and Earth processes that created, shaped, and continue to shape, the landscape we see today. The events recorded by these rocks date back over many millions of years. In order to appreciate, and place these rocks in their true context, it is useful to look very briefly at geological time.

The earth is currently known to be almost 4600 million years old. As such an immense span of time is virtually impossible to imagine, it is helpful to represent the whole of Earth history by a single day (see diagram)*. On this basis, the oldest rocks present within the AONB/EMS, which date back to about 350 million years ago, were formed at around 10.30pm; the Quaternary ice ages started at about one minute to midnight and the whole of human history took place within the last two seconds to midnight!

For convenience of description and interpretation, geologists, like historians, divide time into manageable units to which they give names. Geological time is divided into Periods, as shown in the diagram.



Geological time diagram
Reproduced with permission of Durham County Council

The Geological Story of the Northumberland Coast

The outer layer of the Earth, the part with which we are familiar, consists of a series of huge comparatively thin slabs of rock up to around 100 km thick, known as plates, which effectively float above deeper partially molten rock. These plates, on which occur the Earth's continents and oceans, are in constant motion, in places pulling apart, in places colliding with one another. Although imperceptible to us, on a geological timescale this motion is surprisingly rapid in places, estimated to be roughly the speed at which human finger nails grow.

The nature and distribution of the rocks we see today in Northumberland result from the movement of these continental plates over many millions of years of geological time.

The oldest rocks that crop out at the surface in the AONB are of Carboniferous age and are the product of geological processes that affected what is now northern England between about 350 and 290 million years ago. However, by studying adjoining areas, we know that these Carboniferous rocks rest upon much older rocks that are exposed at the surface today in the Cheviot Hills, the Scottish Borders and along the Berwickshire coast. These now concealed older rocks give us important clues to events that were then shaping the region and which were to influence the succession of rocks which occur today at the surface in the AONB.

To best comprehend the development of this part of Northumberland we must venture back almost 500 million years to the Ordovician Period of Earth history.

At that time the map of the Earth was very different from today. The portion of the Earth's crust that was destined to become Northumberland lay far south of the Equator, beneath the waters of a deep ocean, known to geologists as the Iapetus Ocean, between two huge continents. The northern continent, known as Laurentia contained what would eventually become Scotland, North America and Greenland. The southern continent, known as Avalonia, which lay close to the much larger continental mass of Gondwana, included what subsequently became England, Wales and southern Ireland. By the process of plate tectonics, these two continents moved inextricably closer to one another. As they did so the sediments deposited in the deep ocean were progressively squeezed and began to be pushed downwards into the Earth, a process known as subduction. As a result, volcanoes developed in the area we see today as Wales, the Lake District and parts of southern Scotland. By about 420 million years ago, during the Silurian Period, the continents finally collided, resulting in severe crumpling of the oceanic sediments, and the creation of a huge chain of mountains including the Scottish Highlands and Southern Uplands. The hard grey sandstones and shales of the Southern Uplands and the Berwickshire coast, some of which show spectacular folds due to these severe Earth movements, are the remnants of these oceanic sediments. The original physical union of Scotland and England thus dates back to these vast Earth movements over 400 million years ago.

The line of continental collision, known as the Iapetus Suture, today lies buried deep between the Solway coast and Berwick-upon-Tweed. Although this line has no obvious surface expression today, its presence was to have a fundamental influence on the region's geological history, the rocks that formed there and ultimately the landscape we see today.

At the time of the collision, our area lay a little south of the Equator and formed part of a large continent. The climate was hot and arid and volcanoes were still actively erupting in what is now the Cheviots. Rapid erosion quickly degraded the mountains and piled up huge thicknesses of red sands and gravels which we see today as the Old Red Sandstone of the Scottish Borders and Berwickshire coast.

By about 350 million years ago, at the beginning of the Carboniferous Period, our area lay on or very close to the Equator. Stretching of the Earth's crust, along lines roughly parallel to the Iapetus Suture, resulted in the development of a series of fault-bounded basins heralding a period of around 50 million years during which our area would lie very close to, and on many occasions a little below, sea level. The largest of these, the Northumberland–Solway Trough, was to be the locus of much of the sediment preserved today as the Carboniferous rocks of the AONB.

Early in Carboniferous times, whilst the climate remained arid, thick accumulations of gravels, washed from the ancestors of the Cheviot Hills, and seen today as conglomerate at places such as Roddam Dene, near Wooler, were soon submerged beneath sands, silts and muds washed into the basin by rivers draining from the north, whilst dolomitic limestones, known as 'cementstones' were deposited in ephemeral lakes. Gradually, the climate became more humid and further uplift of nearby upland areas caused wide rivers to spread vast quantities of sand across a wide part of the Northumberland Trough building up the thick accumulations of sand seen today as the Fell Sandstone of the Rothbury hills, the Doddington area and Bowden Doors.

Eventually, subsidence of the Earth's crust caused the region to subside beneath the waters of a warm, shallow tropical sea in which an abundance of lime-secreting organisms produced accumulations of limestone. Into this sea drained large rivers, mainly from a contemporary land mass somewhere to the north and north east, carrying huge volumes of mud and sand, and building deltas on the tops of which lush tropical vegetation thrived. As they were buried, compacted and turned to rock, the muds became the shales we see today; the sands became sandstones; and the remnants of vegetation from the tropical forests were preserved as coal seams.

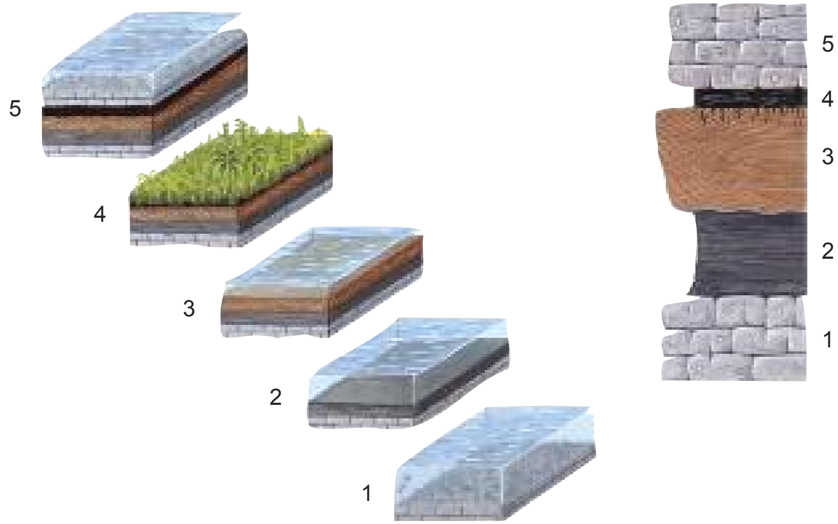
The coal-forming forests were periodically submerged as the tropical sea flooded the area again, only to be followed by the repeated building of river deltas. This repetitive alternation of marine and deltaic environments resulted in the very distinctive succession of rocks that make up much of the Carboniferous succession of Great Britain, Europe and North America. Geologists apply the term 'cyclothem' to these regularly-repeated and predictable successions of limestone, shale, siltstone, sandstone and coal. The cyclothems found in the Lower Carboniferous rocks of northern England are commonly referred to as Yoredale cyclothems, named after 'Yoredale', an old name for Wensleydale in North Yorkshire where these rock successions were first studied in detail. The diagram shown here offers a simplified explanation of the formation of Yoredale cyclothems. Despite many years of research, the formation of cyclothems remains the subject of debate amongst geologists.

Although the detailed history of the Carboniferous Period is complex, throughout time limestone-forming marine intervals gradually became fewer and shorter with coal-forming forests becoming progressively more common and longer-lived, culminating in the major coal-forming episodes of the Coal Measures in the upper part of the Carboniferous succession. Coal Measures rocks occupy only a tiny area in the southern part of the AONB near Amble, but occupy a huge outcrop immediately to the south in the Northumberland Coalfield.

Towards the end of Carboniferous times, a major phase of Earth movements affected much of northern Europe, including the area that was to become Northumberland. During this episode, known as the Variscan Orogeny, the pre-existing rocks were uplifted, tilted, folded and fractured.

Associated with these movements, about 295 million years ago, stretching of the Earth's crust allowed huge volumes of molten rock, or magma, at temperatures of up to about 1,100°C, to rise from deep within the Earth. This never reached the surface, but spread out between the layers of sediment, cooling and crystallising to produce the hard black dolerite of the Whin Sill. As it did so its heat altered, or metamorphosed, the adjacent rocks, turning shales into 'hornfels' and limestones into marble.

After the formation of the Whin Sill, the geological record falls silent for over 290 million years. Any rocks deposited over the area during this long period have long been removed by erosion. Our understanding of the events that continued to affect the area can be deduced, with varying levels of confidence, only by studying rocks in adjoining and more distant areas. These will not be considered further here.



Key
1 Limy ooze on the sea floor hardened into limestone
2 Mud washed in by rivers became shale
3 Sand deposited by river deltas hardened into sandstone
4 Swampy forests grew on top of the deltas and eventually became coal seams
5 The sea flooded the deltas, depositing more limy ooze - and the cycle started again

The formation of Yoredale Cyclothems
© Elizabeth Pickett

Our area's story resumes about 2 million years ago when a remarkable, and as yet unexplained, episode of global cooling caused ice sheets to develop and expand across much of Britain and northern Europe and the adjoining seas. From detailed studies of glacial deposits across this wider region it is clear that ice covered northern Britain, including Northumberland, on several separate occasions. At times, ice may have been up to 1 km thick over parts of northern England. These glacial periods were separated by inter-glacial periods during which the ice cover is known to have melted with, on occasions, the climate becoming much milder than it is today. Almost all of the glacial deposits and landforms in Northumberland date from the most recent cold period, known as the Devensian Glaciation, which lasted from about 25 000 to 11 000 BP (before present). Melting of the last ice cover, which took place with remarkable and unexplained rapidity, as recently as 15,000 to 11,000 years ago, resulted in the formation of a number of post-glacial deposits, including some related to the markedly fluctuating sea level changes caused both by large volumes of meltwater and by the rising of the land surface previously depressed by the weight of glacial ice.

It is important to recognise that since the disappearance of the last ice sheets, Earth processes have shaped, and continue to shape, the landscape we see today. Geological history is long, but is not over. We are privileged to be witnesses to this brief point in the Earth's long and sometimes turbulent history, and unique in the Earth's evolution in being the first of its creatures able to marvel at, and attempt to comprehend, something of the complex processes at work.

Dunstanburgh Castle, one of the Coast's best known landmarks, stands on a promontory formed by the resistant Whin Sill

The Geodiversity of the Northumberland Coast

Geology is not constrained by administrative or political boundaries. True understanding of an area's geodiversity comes from recognising the significance of those features within their wider regional, national and international context. Appropriate comments on this wider context are included in the sections which follow.

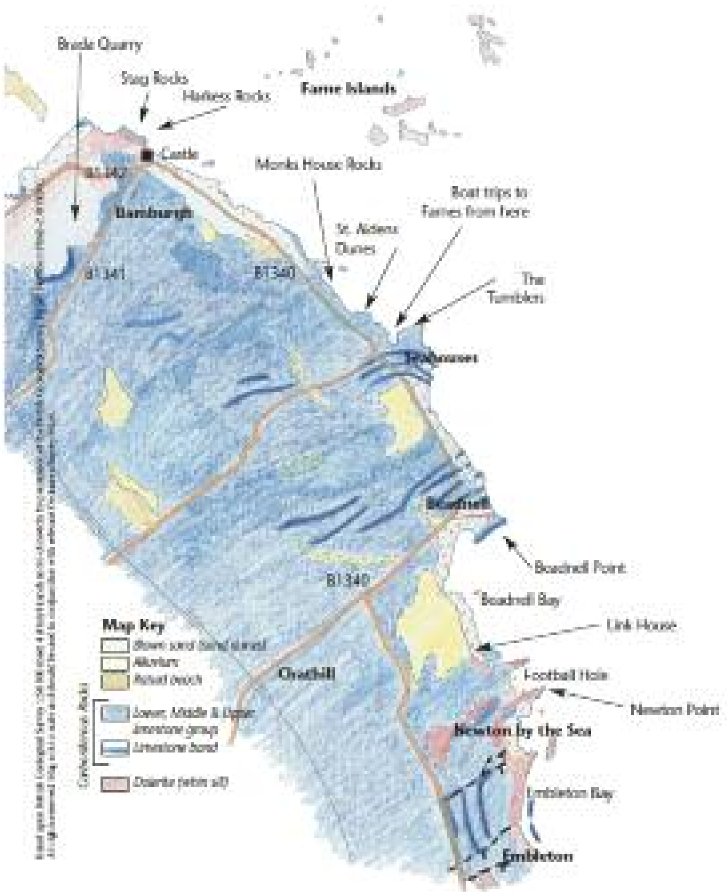
As we shall see, the varied geodiversity of the Northumberland Coast includes much of interest and importance.

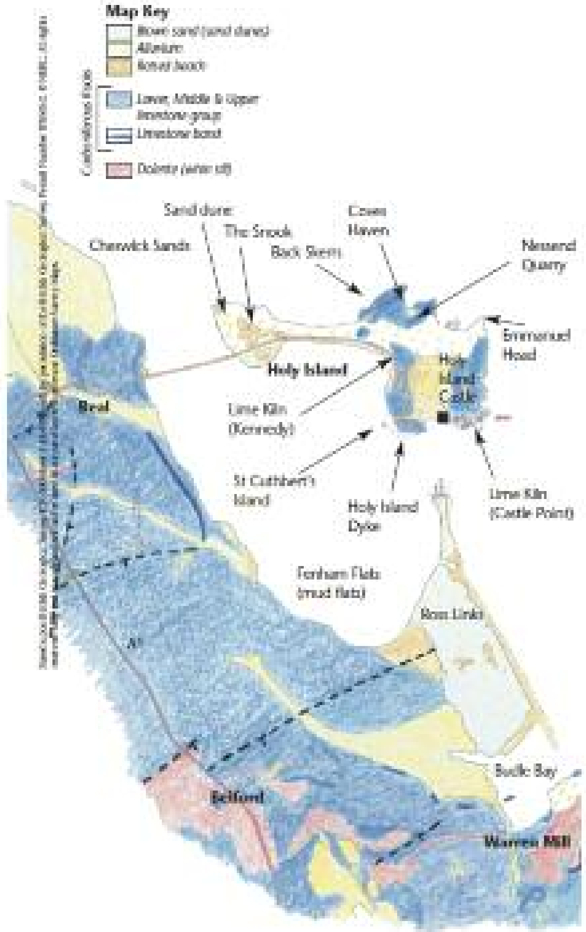
The succession of rocks that crop out at the surface on the coast is shown in the geological column on page 18. In the following pages the essential characteristics of each of these major rock units will be outlined together with general comments on their local and wider scientific importance, their role in influencing landscape character, biodiversity, economic use, settlement patterns etc.

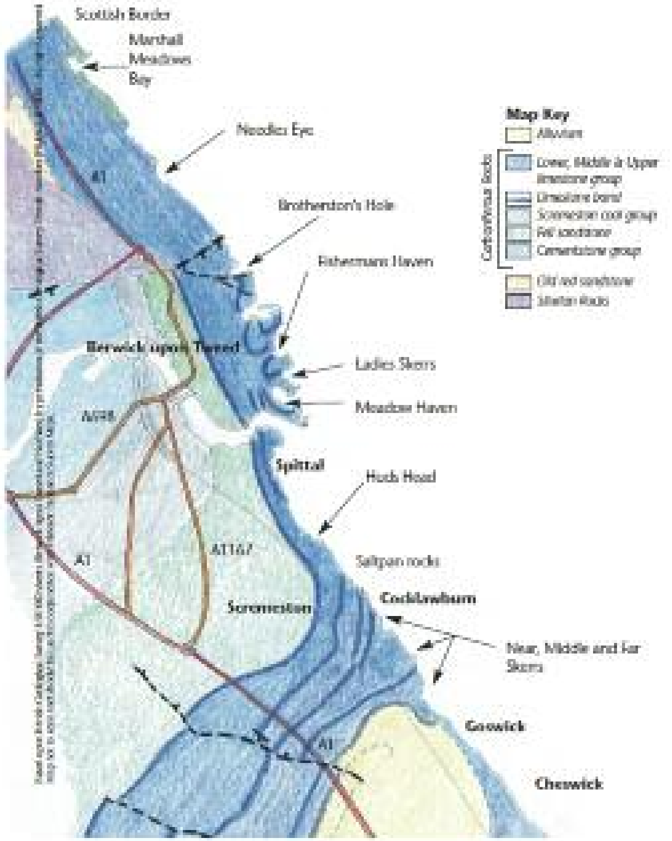
Carboniferous limestones, sandstones and shales exposed on the foreshore at Saltpan Rocks, near Scremerston. The numerous rock pools are important for their marine ecology.

Geological Maps of the Northumberland Coast

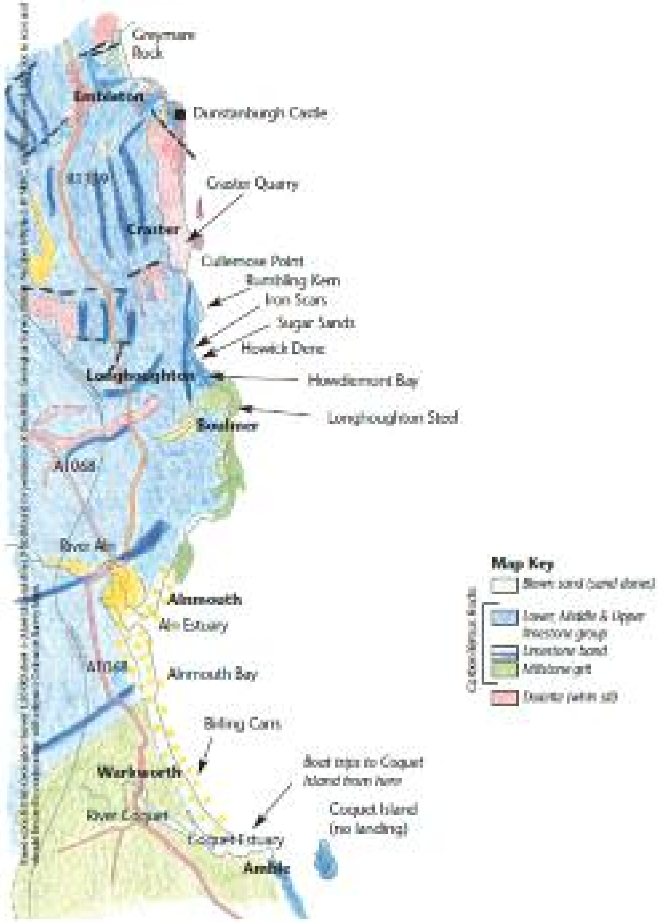
Taken from the Northumberland County Council publication 'Explore the Geology and Landscape of the Northumerbland Coast'. These maps use the terminology current at the time of their production.







Scottish Border
Marshall Meadows Bay
Needles Eye
A1
Brotherston's Hole
Fishermans Haven
Berwick upon Tweed
Ladies Skerrs
Meadow Haven
A698
Spittal
Huds Head
A1167
A1
Saltpan rocks
Scremeston
Cocklawburn
Near, Middle and Far Skerrs
A1
Goswick
Cheswick
Map Key
Alluvium
Lower, Middle & Upper limestone group
Limestone band
Scremeston coal group
Fell sandstone
Cementstone group
Old red sandstone
Silurian Rocks



Greymare Rock
Embleton
Dunstanburgh Castle
B1339
Craster Quarry
Craster
Cullernose Point
Rumbling Kern
Iron Scars
Sugar Sands
Howick Dene
Lo...ghoughton
Howdiemont Bay
Longhoughton Steel
Boulmer
A1068
River Al
Alnmouth
Aln Estuary
A1068
Alnmouth Bay
Birling Carrs
Warkworth
Boat trips to Coquet Island from here
Coquet Island (no landing)
River Coquet
Coquet Estuary
Amb...
Map Key
Blown sand (sand dunes)
Lower, Middle & Upper limestone group
Limestone band
Millstone grit
Dolerite (whin sill)

A simple guide to geological terminology

Like any other discipline, Earth science has its own technical jargon. Whereas many commonly used terms are explained very briefly in the Glossary on page 67, a number of the most fundamental terms and their associated concepts are of sufficient importance to merit the rather fuller explanations offered below.

Geologists recognise three main types of rock, examples of all of which may be found in the AONB/EMS.

Sedimentary rocks comprise almost all of the rocks exposed at the surface within the AONB. These are rocks that were originally deposited as sediments on the sea floor, in lakes, on river banks or in similar environments which have comparable, and understandable, modern counterparts. Over geological time, compaction and a variety of physical and chemical processes, have transformed these sediments into rock. Materials, such boulder clay, peat, the sands of present-day beaches and dunes, etc. are unconsolidated sediments of comparatively recent origin.

Igneous rocks are rocks formed by the cooling and crystallisation of originally very hot molten rock, or magma, from deep within the Earth. The AONB includes one world-famous example of such an igneous rock — the Whin Sill. It was intruded into different levels within the succession of sedimentary rocks. It cannot therefore be easily depicted on diagrams representing geological timescales.

Metamorphic rocks are rocks which, through the effects of heat and pressure have been altered from their original form. In the AONB, some of the sedimentary rocks have been altered, or metamorphosed, adjacent to the Whin Sill.

Stratigraphy is the branch of Earth science concerned with the study of the layers, or strata, in rock successions such as that shown in the geological column on page 18. It provides the means to decipher events and process throughout geological time. We may look at an area's stratigraphy in terms of the nature and composition of the constituent rocks, or in terms of the relative ages of those rock units. Although clearly related to one another, it is important to distinguish between these two concepts. Strict protocols determine the stratigraphical classification of rocks, but the following brief paragraphs introduce the essential differences in two important ways of using stratigraphy.

Lithostratigraphy is the term applied to the succession of rock types, or lithologies, e.g. limestone, sandstone, coal etc. In the AONB, individually recognisable rock units, such as the Eelwell Limestone, or the Scremerston Main Coal, are separately named, but for convenience of description and for ease of depiction on geological maps, it is common practice to designate parts of the rock succession which share certain key characteristics as Formations. Formations typically take their name from a locality or region in which they are particularly well developed. Where a succession of one or more Formations shares a number of broader unifying characteristics, they may be gathered together as Groups.

Within the AONB, the Great, Acre and Eelwell limestones, together with the Acre and Beadnell coals, are some of the rock units which together comprise the Alston Formation. This, together with the Stainmore and Tyne Limestone formations, comprise the larger unit known as the Yoredale Group. The important point to appreciate is that these subdivisions of the geological succession relate to the component rock type, or types.

Chronostratigraphy is a parallel concept to lithostratigraphy and concerns itself with the relative ages, or time divisions, within the component parts of the succession of rocks, irrespective of the rock types present. The dating evidence is derived principally from a study of the fossil content of the rocks. Thus, the Carboniferous System embraces all of the deposits formed during the Carboniferous Period. This is subdivided, as shown in Table 1 on page 18, into smaller time intervals known as Sub-systems and further into Series. Smaller chronostratigraphical intervals, including Stages and Zones are not considered further here. These time intervals allow comparison or correlation with similar rock sequences elsewhere. Thus, for example, the portion of the Northumberland geological succession which can be shown to be of Tournaissian age, is the equivalent of successions of rocks of the same age elsewhere across the globe. Rock successions of Tournaisian age in different places are not necessarily composed of the same rock types, or lithologies: sandstones of this age in Northumberland may be the exact time equivalent of limestones somewhere else.

Both lithostratigraphy and chronostratigraphy offer important insights into aspects of the rocks to which they relate, though it is important that the two sets of nomenclature, and thus concepts, are not confused.In Table 1 on page 18, terms relating to lithostratigraphical classification are shown in green, the chronostratigraphical classification is shown in blue.

Carboniferous Rocks

These rocks were formed during the Carboniferous Period of Earth history, between about 354 to 290 million years ago. The term Carboniferous relates to the worldwide abundance of coal seams within rock sequences of this age. Like the names of many geological periods, 'Carboniferous' was first used in Britain and has long been adopted internationally.

Carboniferous rocks in northern England

Carboniferous rocks comprise one of the most extensive groups of rocks in British geology, and occur extensively across northern England. The great majority of the rocks that crop out at the surface within the AONB are of Carboniferous age. However, in order to appreciate and understand the characteristics and significance of the area's Carboniferous rocks, it is useful to look briefly at the origins of these rocks within the wider context of northern England.

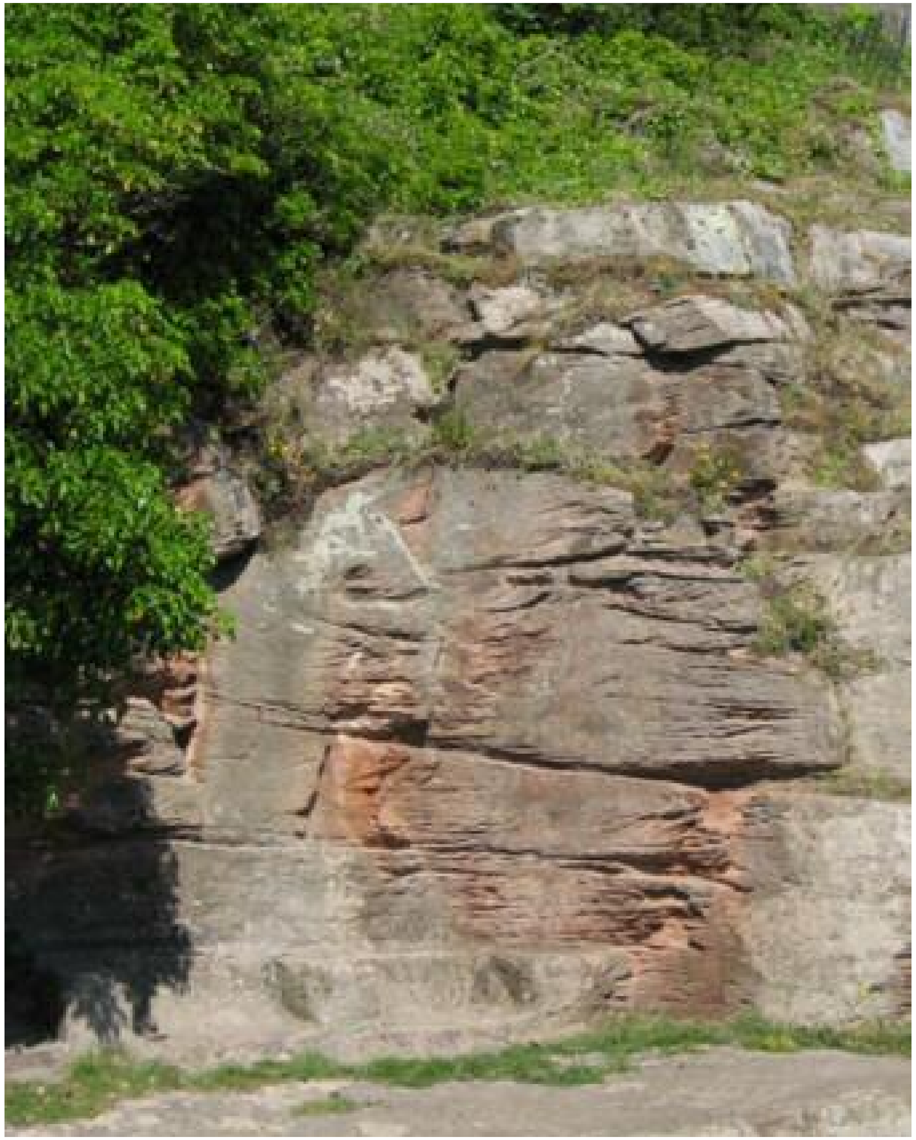
Britain's Carboniferous rocks record a long and rather complex sequence of geological events and associated changing environmental conditions. The following is a brief summary of the most important of these in the evolution of what we see today as the Northumberland Coast AONB.

Throughout Carboniferous time, the Earth's crust beneath what is now Britain subsided at different rates, creating a series of 'troughs' separated by active fault lines from upstanding 'block' areas. Much thicker sequences of sediment accumulated within the more rapidly sinking 'troughs' than over the intervening 'blocks'. Distinctive rock sequences can today be identified in each of these 'block' and 'trough' areas.

Northumberland's Carboniferous rocks, north of the Tyne Valley, were deposited in a broad 'trough' area, known as the Northumberland-Solway Trough. This region of comparatively rapid subsidence during Carboniferous time was bounded on the south by the Stublick–Ninety Fathom Fault system: to the south lay the 'Alston Block', beneath what is today the North Pennines. To the north, the Northumberland–Solway Trough was bounded by the North Solway Fault system, north of which lay another 'block' beneath what is today the Southern Uplands.

The Carboniferous rocks of Northumberland, of which those of the coast form part, comprise a succession, more than 2.5 km thick, composed almost exclusively of sedimentary rocks. A few small outcrops of basaltic lavas, exposed south-west of the Cheviot, principally near Cottonshope, record brief episodes of Carboniferous volcanic activity: no Carboniferous volcanic rocks occur on the coast.

A complex interplay of marine and deltaic environments during Carboniferous times produced a succession of limestones, shales, siltstones, sandstones and coals, in more or



Cross-bedded red sandstone beneath Whin Sill, at Bamburgh Castle.

less regular and predictable rhythmic units, known as cyclothems. Comparatively frequent marine intervals during the Dinantian portion of Carboniferous time resulted in the deposition of numerous beds of limestone. Interbedded units of shale, siltstone and sandstone, reflect the advance of ancient rivers, draining a contemporary land area to the north and east. Beds of sandstone or mudstone, characterised by an abundance of fossilised roots, and known as seatearths, record the growth of lush swamp forests on the deltas built by these rivers. Coal seams, found immediately above these seatearths are the preserved remains of this rich vegetation.

Naming and classifying the Carboniferous rocks of northern England

The naming of rock units began long before the emergence of geology as a scientific discipline. Geological science developed in large part from the simple practical observations and interpretations made by generations of quarrymen and miners. From the beginnings of human civilisation rocks and minerals have been extracted for a variety of purposes including building or other construction materials, as metal ores, or as fuel. For centuries it has been recognised that, in order to work these materials most efficiently, and to secure future reserves, an appreciation and understanding of their distribution, their physical, and to some extent chemical, characteristics was essential. Thus it was that, over the centuries, quarrymen and miners became extremely familiar with the rocks upon which their livelihoods depended. Beds of economic importance, such as many sandstones, limestones and coal seams, acquired local names. The AONB includes many such examples, some of which derive their names from localities within the AONB.

These earliest observations often exhibited considerable insight and sophistication: the earliest attempts at correlating rock units between different locations or regions arose from the need to identify beds, or groups of beds, of economic interest and trace them across country. Many of these named units are identified on Table 1 on page 18. These and others of importance in understanding the geodiversity of the AONB are discussed below.

With the emergence of geology as a scientific discipline, many of these traditional names passed into formal use in the geological literature. Even today, individual beds of limestone, coal seams, and some sandstones still bear their original local names. Information on the origins of the names, type locations and earliest references in the scientific literature, of individual Carboniferous rock units, including many in the AONB, is contained in two detailed volumes published by the Union Internationale des Sciences Géologiques [*International Union of Geological Sciences*] (Whittard and Simpson, 1960; Simpson, George and Blake, 1971).

Geologists today classify Carboniferous rocks within a number of formal Groups and Formations, based upon distinctive internal characteristics relating to the nature and composition (the ***lithology***) of the rocks. This ***lithostratigraphical*** classification is used to describe and interpret the origins of the rocks and to name and identify them on geological maps. Study of their contained fossils enables a parallel classification of these rocks based upon their age to be erected. This ***chronostratigraphical*** classification allows these rock sequences to be compared, or correlated, with rock sequences of similar age elsewhere. The relevant ***lithostratigraphical*** and ***chronostratigraphical*** subdivisions of the Carboniferous rocks of the AONB and adjoining areas is shown in Table 1 on page 18.

Whereas the names of individual beds of, for example, limestone, sandstone or coal, have remained more or less constant over the course of time, the names applied to larger subdivisions or groups of rock units have changed as ideas on stratigraphical classification and correlation have evolved. Research into the classification of Carboniferous rocks across the whole of Great Britain, mostly undertaken by the British Geological Survey in the past decade, has led to a fundamental revision of the naming of Carboniferous strata over wide areas, including Northumberland. Although intended to aid understanding of these rock sequences, and ultimately to simplify national nomenclature, much of this terminology has yet to appear widely outside of the specialised technical literature. The stratigraphical nomenclature used on 1:50000 scale geological maps, and their accompanying memoirs, that cover the AONB, is that employed at the time of their publication (1925–1934). Table 1 provides a summary of the newly adopted subdivisions and a guide to their previous identities.

In the following pages, the essential characteristics of the Carboniferous rocks of the AONB, and immediately adjoining areas, are outlined briefly in chronological order.

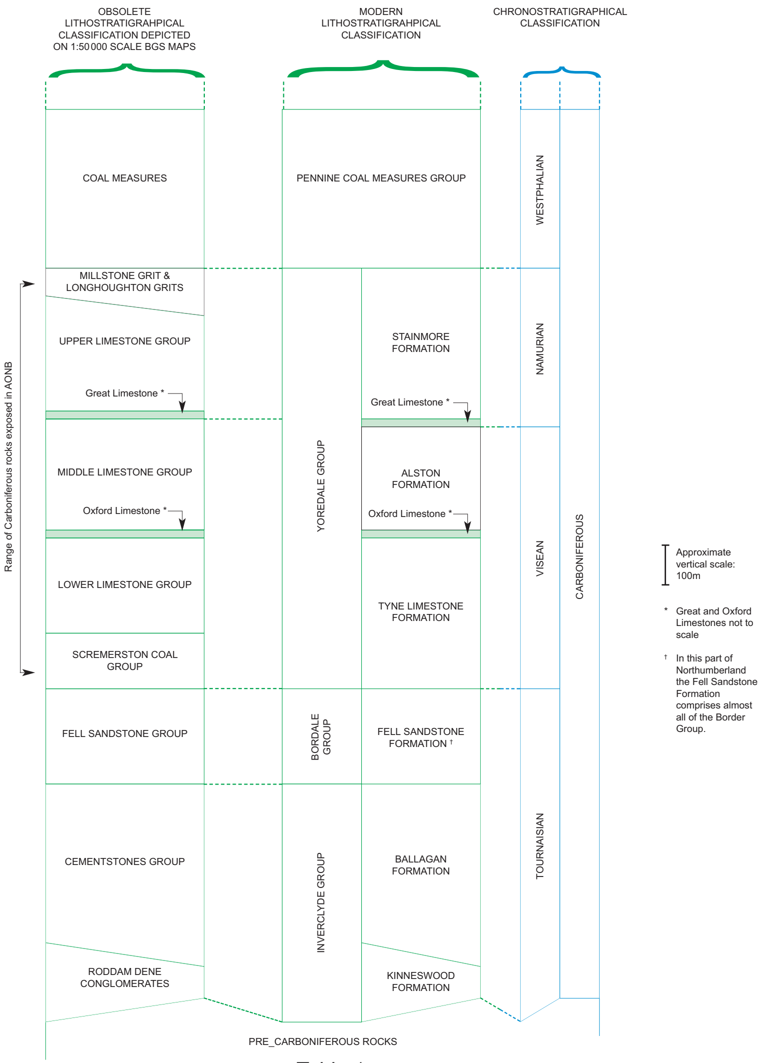


Table 1:
Classification of Carboniferous rocks in the AONB and adjoining parts of Northumberland.

Carboniferous rocks within the AONB/EMS and adjoining areas

To appreciate fully, and in context, the nature and significance of Carboniferous rocks within the AONB, it is important to include brief comments on some of the rocks in immediately adjoining areas.

Inverclyde Group

Because the oldest Carboniferous rocks deposited in north Northumberland resemble more closely those rocks deposited in early Carboniferous times in central Scotland than those laid down further south in England, the British Geological Survey has recently included these Northumbrian rocks within the Inverclyde Group.

The ***Kinneswood Formation*** (the name is taken from the Kinneswood area in central Scotland, near Loch Leven), at the base of this Group, includes beds of conglomerate, sandstone and shale, known from a number of localities close to the Cheviots. One of the best known units within these rocks is the Roddam Dene Conglomerate, magnificently exposed in the steep sides of Roddam Dene near Wooperton. This comprises a thick succession of rocks dominated by coarse conglomerates that formed as accumulations of pebbles and boulders washed by ephemeral streams in a semi-arid environment, from the newly created uplands of the Cheviot area, in early Carboniferous times.

The overlying ***Ballagan Formation*** (the name is derived from Ballagan Glen, north of Glasgow) includes the thick succession of shales, siltstones, sandstones and thin limestones long known in Northumberland as the ‘Cementstones Group’. These rocks have been interpreted as the products of deposition in a wide lagoonal, coastal flat and estuarine environment which, on occasions, was subject to evaporation and desiccation. The numerous thin limestones are commonly rich in clay and were formerly referred to as ‘cementstone’, hence the former name of the succession containing them. The generally soft rocks of the Ballagan Formation are rather easily eroded and give rise to the mainly low-lying ground fringing the Cheviot Hills and extending towards the Scottish Border near Coldstream. Much of their outcrop is concealed beneath glacial and other superficial deposits.

Although these two formations do not crop out within the AONB, they are exposed at the surface a few kilometres to the west and further north on the coast. Due to the general regional easterly or south-easterly dip of Northumberland’s Carboniferous rocks, the Ballagan Formation is almost certainly present at depth beneath the younger Carboniferous rocks of the AONB. Rocks of the Kinneswood Formation are probably of much more limited extent and may not extend far eastwards beneath the AONB.

An appreciation of the nature and origins of these rocks is important in understanding the evolution of Northumberland during early Carboniferous times, thus enabling the rocks of the AONB to be seen in their wider geological context. However, as rocks of the Inverclyde

Group do not crop out within the AONB, their impact upon landscape, biodiversity, economic use, etc. are not discussed further here. More detailed discussion of these rocks within Northumberland, may be found in the geodiversity Audit and Action Plan for the Northumberland National Park (Lawrence et al., 2007).

Border Group

In the latest lithostratigraphical classification of eastern Northumberland's Carboniferous rocks, the Border Group contains only one Formation, the ***Fell Sandstone Formation***. This comprises a thick succession dominated by hard gritty sandstones, which locally contain conspicuous scattered quartz pebbles. Beds of shale are also known, but are rarely exposed at the surface. The sandstones are well-known for finely-preserved sedimentary structures including spectacular examples of cross-bedding. These attest to the formation's deposition within a major system of river channels during early Carboniferous times. The Fell Sandstone takes its name from its conspicuous role in forming the very distinctive fell country of prominent escarpments and crags in the Rothbury, Simonside, Chillingham and Doddington areas.

As with the rocks of the Inverclyde Group, the Fell Sandstone Formation dips gently eastwards beneath the AONB where its rocks are concealed beneath later Carboniferous rocks. Also like these older rocks, an appreciation of the nature and origins of Fell Sandstone helps to inform understanding of the geological evolution of Northumberland and enables the rocks of the AONB to be seen in their wider geological context.

As rocks of the Border Group and Fell Sandstone Formation do not crop out within the AONB, their impact upon landscape, biodiversity, economic use, etc. are not discussed further here. More detailed discussion of these rocks within Northumberland, may be found in op cit. Lawrence et al., 2007.

Yoredale Group

This newly defined group derives its name from 'Yoredale', an old name for Wensleydale, the North Yorkshire dale where these rocks were first studied in detail. Most of the carboniferous rocks exposed at outcrop within the AONB belong to the Yoredale Group.

Reference to Table 1 reveals that this large subdivision of Carboniferous lithostratgraphy includes units known previously as the Scremerston Coal Group, the Lower, Middle and Upper Limestone groups, and the Millstone Grit and Longhoughton Grits. Further comments on the equivalence of these well known and traditional subdivisions, with the formations defined in the modern terminology follow.

The distinguishing characteristic of the Yoredale Group is the remarkable succession of repeated units of rhythmically deposited sediments, known as cyclothems. The nature of these units, together with very brief comments on their mode of formation, have been given above.

Section through a typical carboniferous cyclothem. The Eelwell Limestone and underlying beds at Beadnell.

In much the same way that previous generations of geologists subdivided this succession of rocks into the Lower, Middle and Upper Limestone groups, the modern classification subdivides the Yoredale Group into three formations. As in past classifications, these sub-divisions are based mainly upon the relative abundance of certain rock types within the succession. These characteristics will be explained more fully below for each of the named formations.

Individual rock types, or lithologies, are commonly similar throughout the Yoredale Group succession. Thus, there is usually little to distinguish sandstones or shales in the Tyne Limestone Formation from those in either the Alston or Stainmore formations. Before outlining briefly the characteristics of these individual formations, it is appropriate to review the essential characteristics of the main Yoredale Group rock types within the AONB.

Limestones are usually compact mid to dark grey rocks in which bedding is usually conspicuous as thick beds or 'posts'. The dark colour of these rocks, compared with that of Carboniferous limestones in, for example, Yorkshire or Derbyshire, is due to significant amounts of impurities such as mud or bitumen. A feature of many Northumberland limestones, including many along the coast, is the distinctive oily, or foetid, smell emitted when they are struck with a hammer, as a result of this high organic content. Most of the limestones are rich in fossils of marine creatures. Whereas these are mostly rather fragmentary and commonly difficult to distinguish, especially on freshly broken surfaces, clearly recognisable fossils of complete, or nearly complete, corals, brachiopods, molluscs and crinoids are generally common. More rarely, gastropods, algae, sponges and fragments of trilobites may be found. Limestones consists mainly of the mineral calcite ($CaCO_3$), though locally this is partly replaced by dolomite (($CaMg(CO_3)_2$), giving the rock a dull buff or pale brown colour.

The Sandbanks Limestone exposed in old quarry workings near Coves Haven, Holy Island.

Shales, more properly called ***clay rocks*** or ***mudstones*** are composed predominantly of clay mineral particles and may be very variable in appearance. Most are medium or dark grey, though where significant amounts of iron minerals are present they may assume a dark brown colour on weathering. True shales are finely laminated and split readily into thin sheets. Mudstones typically exhibit no clear lamination and may be rather massive rocks with a rather blocky appearance. Some shales, especially those that overlie limestones, may be markedly calcareous, commonly with an abundance of marine fossils of the sort found in limestones. Many shales are barren of obvious fossils: some contain plant fragments and some yield fossils of freshwater molluscs. Several shale beds contain scattered nodules, or layers of nodules of clay ironstone (see below).

Shales with thin partings of sandstone at Saltpan Rocks, near Scremerston.

With increasing silt content, shales pass imperceptibly into siltstones.

Siltstones closely resemble many shales or mudstones, though are distinguished by being composed of silt, rather than clay, particles. Like shales, siltstones are typically grey when fresh, though commonly assume a brown colour on weathering. Many exhibit prominent lamination and trace fossils including burrows or trails may locally be conspicuous. Where such burrowing activity is intense, the sediment may have a thoroughly mixed appearance, a feature known as ***bioturbation***.

Laminated siltstones exposed at the cliffs in Saltpan Rocks, near Scremerston.

With increasing grain size of the constituent particles, siltstones may pass imperceptibly into sandstones.

Sandstones comprise a major proportion of the Yoredale Group rocks of the AONB. These are very variable rocks, ranging from very fine grained sandstones resembling coarse-grained siltstones, to very coarse-grained rocks in which pebbles of quartz and other minerals may be clearly visible to the naked eye. In common with most of the Carboniferous sandstones of northern England, the sandstones of the AONB typically contain significant amounts of clay, usually in the form of degraded grains of the mineral feldspar. Some of the very coarse-grained sandstones at Longhoughton Steel are remarkable for their conspicuous grains of comparatively fresh feldspar. Some sandstones are massive in appearance, in some instances with few signs of bedding, though most exhibit some remnants of bedding. This may be extremely prominent, especially in sandstones rich in mica grains which commonly accentuate and define individual bedding planes. Ripple-marked surfaces are common in some sandstones, clearly recording the effect of moving water, exactly comparable to the formation of modern ripples on the shore. Many sandstones exhibit conspicuous cross-bedding in which internally inclined layers within the bed indicate the direction of current flow in the water in which the sandstone was deposited. The internal lamination of some sandstones is conspicuously distorted due to the effects of Earthquake shocks during Carboniferous times. Some sandstones contain a variety of trace fossils, including amphibian footprints at one locality in Howick Bay. Sections of fossilised plant roots or stems may also be found locally.

Most of the AONB's sandstones are pale brown or buff in colour, though striking pink and red colours are seen in some sandstones in the north of the AONB, for example at Hud's Head, and in the stone used in the construction of Lindisfarne Priory.

Cross-bedded red sandstone beneath the Whin Sill at Bamburgh Castle

Seatearths are not a single rock type. The name indicates any rock, typically full of fossilised rootlets, that is the preserved soil layer upon which coal-forming vegetation grew. Seatearths may be mudstones, siltstones or sandstones. Sandstone seatearths are commonly very rich in silica, due to the strongly leaching conditions within the ancient soil environment. Such rocks are commonly known as 'ganisters'. Mudstone seatearths may be very pale grey or almost white rocks in which the dominant clay minerals are very aluminium-rich, again due to the strongly leaching conditions in the original soil. These rocks are commonly known as 'fireclays'.

A thin coal seam underlain by a sandstone seatearth in the cliffs at Howick Bay.

Clay ironstones are compact dense, heavy rocks, typically found as rounded or flattened oval nodules scattered through, or concentrated in bands in, mudstones or siltstones. They are composed mainly of impure concentrations of the iron carbonate mineral siderite ($FeCO_3$) and formed by segregation of iron minerals within the surrounding rock. With iron contents of up to around 30%, they were locally worked as iron ores.

Clay ironstone nodules in shale at Rumbling Kern.

Coals consist almost exclusively of the fossilised remains of plant tissue, though most seams contain thin partings of muddy or silty sediment. Most of the AONB's coals are bituminous coals and typically exhibit a pronounced internal layering of alternately bright and duller components.

The Acre Coal, underlain by a sandstone seatearth at Saltpan Rocks, near Scremerston.

The modern classification of Carboniferous rocks subdivides the Yoredale Group into the following three separate formations.

The ***Tyne Limestone Formation*** (the name refers to its wide distribution throughout the valleys of the North and South Tyne) comprises the succession of rocks between the top of the Fell Sandstone Formation and the base of the Oxford Limestone. It therefore corresponds to those rocks formerly separately identified as the Scremerston Coal Group and the Lower Limestone Group.

Much of the succession consists of beds of limestone, mudstone, siltstone and sandstone though thin coal seams are locally common in the lower part of the unit, formerly referred to as the Scremerston Coal Group.

Tyne Limestone Formation rocks crop out in the extreme north of the AONB north of Cocklawburn. Notable exposures here include sections through distinctive pink sandstones. Further south, rocks of the Tyne Limestone Formation occupy a wide outcrop between Beal and Elwick, though coastal exposures are few in this area. On the coast these rocks crop out in a small area south of Bamburgh, though here again exposure is very limited.

Inland, rocks of the Tyne Limestone occupy an almost continuous, and wide, outcrop immediately to the west of the AONB.

The ***Alston Formation*** (named from Alston in the Northern Pennines) of the modern classification extends from the base of the Oxford Limestone to the top of the Great Limestone. It is therefore almost the exact equivalent of the former Middle Limestone Group, though the Great Limestone, formerly grouped as the basal unit of the obsolete Upper limestone Group, is included within the Alston Formation.

As with the Tyne Limestone Formation, mudstones, siltstones and sandstones comprise the greater proportion of the succession. However, the formation is distinguished by containing most of the major limestones of the AONB, though these comprise only a comparatively small proportion of the total rock succession. Numerous sandstones are also present and thin coal seams are common, though these are fewer and thinner than those found near the base of the underlying Tyne Limestone Formation.

Rocks of the Alston Formation occupy much of the coast south from Cocklawburn to Beal. Magnificent exposures of these rocks, including some spectacular anticlinal folds within the Eelwell Limestone, beautifully fresh sections through coal seams and associated beds, including seatearths, and minor faults, are to be seen around Saltpan Rocks at the northern end of Cocklawburn beach. Fine sections of these rocks are also exposed in the Near, Far, and Middle Skerrs, Cheswick Black Rocks and parts of the old limestone quarries at Cocklawburn. Between Cocklawburn and Beal, rocks of the Alston Formation are generally concealed beneath superficial deposits along much of this length of coast.

Their outcrop resumes at Elwick and continues almost without interruption, save for Whin Sill intrusions, as far south as Howick.

Reddish sandstones belonging to the Alston Formation are conspicuously exposed beneath the Whin Sill adjacent to the cricket field at Bamburgh. Particularly fine exposures of these rocks may be seen at numerous points on the coast around Seahouses and Beadnell. The Oxford Limestone is well exposed at Greenhill Rocks and Monkstone Rocks and at the reefs known as 'The Tumblers', a short distance north of Seahouses, the Eelwell limestone, here with an abundance of fossils, is well exposed.

The coast between Seahouses and Beadnell offers some of the finest and most complete sections through rocks of the Alston Formation anywhere in northern England. There are numerous excellent exposures of limestones, sandstones and some coal seams with their associated seatearths.

Alston Formation rocks are well exposed in the cliffs and foreshore for about 1 km south of Cullernose Point. In addition to fine sections of the fossil-rich Acre Limestone, there are good sections through sandstones, mudstones and siltstones. Some of the nodules found within the shales beneath the Acre Limestone are unusual in containing significant concentrations of galena (PbS) and sphalerite ((Zn,Fe(S)), though the minerals are not here visible to the naked eye (See Minerals on page 48). The cliffs here also expose magnificent sections through the Howick Fault, which here juxtaposes Alston formation rocks on its north side against Stainmore Formation rocks on the south (see the section on Geological structures, page 43).

The ***Stainmore Formation*** (the name is derived from the Stainmore area of southern County Durham where it was first identified as a major stratigraphical unit), which extends from the top of the Great Limestone to the base of the Coal Measures, corresponds broadly to the former Upper Limestone Group, minus the Great Limestone, but includes sandstones previously described as the 'Millstone Grit' or 'Longhoughton Grits'.

Like the underlying Tyne Limestone and Alston formations, the Stainmore Formation includes many beds of mudstone and siltstone. In addition, it includes a few thin limestones, though many fewer than in the underlying Alston formation, together with a number of thin coals and numerous beds of sandstone. In previous classifications of Northumberland geology, a group of prominent, mainly coarse-grained, sandstones, including the Longhoughton Grits, were assumed to be the local representatives of the Millstone Grit of the central and southern Pennines. This comparison is no longer regarded as valid and no true representatives of the Millstone Grit are today recognised in Northumberland.

Stainmore Formation rocks underlie the coast southwards from the Howick Fault, about 1 km south of Cullernose Point. Fine exposures of these rocks may be seen on the coast around Howick where notable features include the sandstone cliffs at Rumbling Kern. Sandstone was quarried here as building stone. A feature of particular interest here is a bed of sandstone in which large scattered blocks of coal may be seen. This, together with the well-developed cross-bedding in the sandstone, provide clear evidence of the strong currents which, during Carboniferous times, transported the sand together with the slabs of peat which are today preserved as blocks of coal. There are also good exposures here of the Howick Limestone.

A further notable feature of these rocks is the former presence, on the surface of a bed of sandstone, to the south-east of Howick Haven, of the fossilised footprints of a Carboniferous amphibian (see the section on Fossils).

Some sandstones exposed at Rumbling Kern and in Howdiemont Bay, exhibit well-developed cross-bedding, which is in places strikingly distorted, almost certainly as a result of disturbance of the then soft sand by earthquake shocks during Carboniferous times.

A thin coal seam underlain by a sandstone seatearth in the cliffs at Howick Bay.

From Longhoughton Steel southwards to Seaton Point, the coast exposes sandstones belonging to the Longhoughton Grits. These locally very coarse-grained sandstones rest unconformably on an eroded surface of older Carboniferous rocks, resulting from an episode of erosion during Carboniferous times. Recent findings elsewhere in Northumberland, for example at Shaftoe Crags (Young and Lawrence 2002), suggest that sporadic Earth movements during Carboniferous times may have resulted in local erosion of sediments and the formation of local unconformities of this sort. The local abundance of fresh feldspar grains within parts of the Longhoughton Grits, is evidence of the very rapid transport and deposition of these sands during Carboniferous times.

Carboniferous rocks in the landscape

Whereas the outcrop of Carboniferous rocks occupies by far the greatest proportion of the surface geology of the AONB, these rocks are widely concealed beneath an extensive mantle of Quaternary deposits.

However, Carboniferous rocks are well exposed over substantial parts of the coast. Whereas all of the major rock types may be seen in places in the sea cliffs, the most resistant limestones and sandstones are responsible for some of the ANOB's most conspicuous coastal rocks and reefs. Marine erosion of the weaker, less resistant, shales and siltstones has contributed to the formation of bays between outcrops of more resistant rock.

Inland, natural exposures are less numerous, though a number of the limestones, and some sandstones, particularly those within the Alston Formation, where free of 'drift' cover, give rise to low scarp ridges. A number of the limestones and sandstones have been quarried, locally on a considerable scale. Prominent limestone quarries, together with their associated spoil heaps and kilns, remain conspicuous landscape features at Cocklawburn, Holy Island, Seahouses, Beadnell and Littlemill (see Mineral Extraction, page 50).

Buildings are essential landscape elements. The role of Carboniferous rocks in giving a distinctive local character to these buildings, and thus an additional aspect of their impact on the AONB's landscape, are outlined in the section on Buildings and the Built Environment, page 54.

Carboniferous rocks and biodiversity

In coastal cliffs and reefs, a variety of Carboniferous rocks provide substrates for a range of birds and shoreline and marine plants and animals.

Inland, exposures of these rocks also offer important substrates for a range of lower plants. Where Quaternary deposits are thin or absent, Carboniferous rocks provide the parent mineral components of soils, and thus directly influence plant assemblages and indirectly the dependent invertebrate, particularly insect, fauna.

Of particular note are outcrops of limestone, where the associated soils typically exhibit comparatively high pH values. Areas of truly natural limestone grassland are small within and adjacent to old limestone quarries, though soils developed on areas of limestone-rich spoil offer semi-natural limestone grassland habitats. The rather extensive areas of limestone spoil adjacent to the Cocklawburn quarries supports important populations of calcicolous species.

Economic use of Carboniferous rocks

The former working of limestone, sandstone, coal and iron ore from the AONB's Carboniferous rocks are discussed in the section on 'Mineral extraction', page 50.

Wider significance of the AONB's Carboniferous rocks

The Northumberland coast offers some of the finest, and most complete, sections through the lower Carboniferous rocks of northern England. They therefore provide vital opportunities both to demonstrate the essential characteristics of these rocks, and to undertake original research on these rocks and the processes that created them. Such research can contribute not only to the understanding of British Carboniferous geology, but to the understanding of Carboniferous rocks and sedimentary processes worldwide.

Carboniferous rocks offshore within the EMS

Whereas the distribution and configuration of Carboniferous rocks onshore is well known from published geological maps, much less is known offshore. The 'solid' edition of the BGS 1:250 000 scale Farne Sheet depicts the offshore geology, though at a small scale and in an extremely generalised way which does not identify the subdivisions of the Carboniferous rocks at group or formation level.

The Acre Limestone exposed on the coast at Snipe Point, Holy Island. Limestone, which formed as the accumulated remains of Carboniferous sea creatures, 320 million years ago, today provides a fine substrate for a variety of modern marine animals and plants.

Permian Rocks

Permian rocks formed during the Permian Period of Earth history which extended from about 295 to 245 million years ago. The name Permian is derived from the Perm area of Russia, where these rocks were first studied.

Permian rocks within the AONB

Permian rocks do not crop out within the onshore area of the AONB. The nearest onshore outcrops lie several miles further south, in isolated outliers at Cullercoats and Tynemouth: south of the River Tyne a continuous narrow outcrop of Permian rocks extends south to the Midlands.

Permian rocks offshore within the EMS

The ‘solid’ edition of the BGS 1:250 000 scale Farne Sheet depicts the offshore geology (including the Permian rocks) of the entire EMS, though at a very small scale and in a very generalised way. The Permian rocks in the offshore area to the south of the AONB and EMS are depicted in more detail on the recently published BGS 1:50 000 scale sheet 10 (Newbiggin). Permian rocks underlie a huge area of the North Sea, with the western edge of their outcrop lying approximately 10 kms east of the Farne Islands and about 12 kms east of Amble. Small thicknesses of these rocks are therefore likely to underlie parts of the eastern extremities of the EMS.

Knowledge of these rocks comes mainly from numerous offshore boreholes, drilled both for coal and hydrocarbon exploration. The Coal Measures rocks of the North East Coalfield dip beneath the Permian rocks when followed eastwards beneath the North Sea, and these Permian rocks are locally very important reservoirs for North Sea gas.

The Permian rocks of this part of the North Sea comprise part of the Zechstein Group, a succession of dolomites and impure limestones with beds of anhydrite. These limestones are the equivalents of the Magnesian Limestone of the Cullercoats and County Durham areas. Poorly cemented sands belonging to the Rotliegende Group, which occur locally beneath the limestones are the offshore equivalents of the Yellow Sands of the Cullercoats, Tynemouth and County Durham areas.

Permian rocks, landscape and biodiversity

Whereas little appears to be known about the impact of these rocks on submarine biodiversity, the widespread coverage of their outcrop by recent seabed sediments is likely to render any such impact very small.

Intrusive Igneous Rocks — The Whin Sill swarm

Igneous rocks are rocks formed by the cooling and crystallisation of originally very hot molten rock, or magma, from deep within the Earth. Magma extruded, or erupted, at the surface of the Earth is known as lava. Depending upon its chemical composition, lava cools to form a variety of ***extrusive*** igneous rocks. When magma does not reach the surface, it may be intruded between layers or masses of pre-existing rocks. Here it cools and crystallises and, depending upon its chemical composition, gives rise to a range of ***intrusive*** igneous rocks. Intrusions of igneous rock may take a variety of forms, but two of these are of particular importance in the AONB: roughly horizontal, sheet-like intrusions, more or less parallel or concordant with the adjoining, or country, rocks, are known as sills; roughly vertical, wall-like, intrusive bodies are known as ***dykes***. Millions of years of erosion may then expose these intrusive rocks at the surface. A variety of complex analytical techniques may be used to date the crystallisation of these rocks. These dates, when interpreted with other geological evidence, provide an extremely important means of establishing accurate dates for key events in Earth history.

Introducing the Whin Sill swarm

Deep-seated stretching and fracturing of the Earth's crust during late Carboniferous to early Permian times, about 295 million years ago, enabled huge volumes of magma to rise from deep within the Earth. It did not reach the surface, but spread out between the layers of Carboniferous rocks where it cooled and crystallised to form the extensive suite of sills and dykes, collectively referred to today as the Whin Sill swarm.

The following very brief summary introduces those aspects of the Whin Sill that are vital to understanding its fundamental place within the geodiversity of the AONB/EMS. More detailed descriptions, together with references to some of the more technical literature, will be found in the publications listed in the section on Information Sources and the selected bibliography.

The Whin Sill swarm underlies an area of more than 4,500 square kilometres of North East England. Its rocks reach the surface in an arcuate outcrop that extends southwards from around Holy Island and the Kyloe Hills, through central Northumberland, along the escarpments of the Hadrian's Wall country and the North Pennine escarpment to Lunedale and Teesdale. From this surface outcrop, the sills dip generally eastwards and south-eastwards beneath southern Northumberland and eastern County Durham.

The sills remain concordant with the bedding of the Carboniferous country rocks over large areas, though in places they abruptly change their stratigraphical horizon in a series of steps. Over much of the outcrop the sill occurs as a single sheet, or leaf, but in places two or more sheets or leaves, may be present one above the other: up to five such leaves occur in the Kyloe Hills, a short distance to the west of the AONB.

Bamburgh Castle occupies a naturally defensive site on a spectacular promontory of Whin Sill dolerite. The base of the sill, in contact with reddish Carboniferous sandstone, is exposed at the foot of the cliffs near the War Memorial.

In places large raft-like masses of country rock, detached by the intruding magma, and known as xenoliths, occur within the main body of the sills.

Associated with these sills is a series of vertical dykes. Four belts of *en echelon* dykes cross north-east England. From the north, these comprise the Holy Island, High Green, St Oswald's Chapel and Hett echelons. The first three occur in Northumberland: the fourth lies in County Durham.

The sills and dykes of the Whin Sill swarm are composed of dolerite, commonly known throughout Northumberland as 'whinstone'. Dolerite is a fine- to medium-grained, dark-grey to greenish-grey crystalline rock composed mainly of the minerals plagioclase feldspar, pyroxene and iron and titanium oxides. A feature of the Whin Sill swarm is the continuity of its mineralogical and chemical composition across the whole of its wide outcrop. Most abundant is fine- to medium-grained dolerite, though very fine-grained, almost glassy, varieties of dolerite occur as narrow selvages where the magma cooled, or chilled, very rapidly against the much cooler country rocks. In places, very coarsely-crystalline dolerite, known as dolerite pegmatite, occurs near the centre of the intrusions, and in places there are small concentrations of pink felsitic material, though these rocks are uncommon in the AONB.

Vein of pink felsitic rock within a block of grey Whin Sill dolerite in a wall at Craster. These felsitic veins are comparatively common at nearby Cushat Shiel, on the coast near Dunstanburgh Castle.

In places, rounded cavities, up to a few centimetres across, and known as vesicles, represent pockets of gas within the molten magma. Most commonly these have been filled with later formed minerals such as calcite or quartz: such filled cavities are known as amygdales.

Calcite-filled amygdales in Whin Sill dolerite at Harkess Rocks.

The rocks adjacent to the sills and dykes, and the xenoliths of country rock, have usually been altered, or metamorphosed, by the great heat of the intrusion. These metamorphic rocks are discussed below.

A common, and very striking, feature of the Whin Sill dolerite is the conspicuous pattern of vertical fractures, along which the rock breaks readily into rough hexagonal columns. This columnar jointing, which is a common feature of many sills and lavas, formed by contraction of the rock during its final stages of cooling. Spectacular though this jointing is in parts of the Whin Sill it does not match the regularity of the columnar jointing seen in the basalts of the Giant's Causeway and Fingal's Cave, on the Hebridean Isle of Staffa.

Cullernose Point. The Whin Sill here exhibits perhaps the finest example of columnar jointing to be seen along the coast.

Radiometric dating of the Whin Sill dolerite indicates that it was intruded about 295 million years ago. Detailed studies of magnetic minerals within the dolerite suggest that, at the time of its intrusion, the area we know today as North East England lay within tropical latitudes.

Naming the Whin Sill

Like so many names used in geology throughout the world, that of the Whin Sill is derived from the everyday vocabulary of quarrymen and miners. For centuries Northumbrian miners and quarrymen have used the term 'sill' for any more or less horizontal body of rock, irrespective of its mode of origin. Thus, in parts of northern England we encounter, for example, the Grindstone Sill, a sandstone well-suited to making grindstones or millstones, the Slate Sills, a group of sandstones suitable for making roofing slabs, and many others. 'Whin' is an old term used by quarrymen for any very dark coloured hard rock that is difficult to shape. It is said that the word 'whin' derives from the distinctive whistling "whinnnn…" noise made by fragments as they are broken from large blocks, though the common occurrence of gorse, or whin, bushes on its outcrops have also been cited as the origin of its name.

When the intrusive nature of Northumberland's Whin Sill was established in the 19th century, the term 'sill' was quickly adopted by geological science worldwide for all such roughly horizontal concordant intrusions. The Whin Sill is thus the original sill of geological science.

The Whin Sill within the AONB/EMS

This suite of intrusive igneous rocks is one of Northumberland's best known geological features and is of particular importance in the AONB/EMS.

Within the AONB, parts of the Whin Sill swarm crop out on Holy Island (Lindisfarne), the Farne Islands, between Budle Bay and Bamburgh, near Newton by the Sea, and between Dunstanburgh Castle and Howick. Over much of the AONB, and adjoining country, the Whin Sill comprises sheet-like sills of dolerite, though narrow vertical dykes are known, for example at Boulmer, Embleton Bay and south of Cullernose Point.

Dyke of Whin Sill dolerite cutting Carboniferous rocks south of Cullernose Point.

Although the intrusions crop out widely inland, where they form important landscape features and may be seen in numerous abandoned quarries, the finest exposures of these rocks are to be seen in coastal cliffs, islands and reefs. Excellent sections are also exposed in working and recently abandoned quarries a short distance west of the boundary of the AONB.

Such is the quality and geological importance of the coastal exposures that much of shoreline outcrop of the Whin Sill within the AONB lies within a number of sites protected under the Geological Conservation Review (GCR). Detailed descriptions and interpretations of the numerous features of interest exposed in these areas are to be found in the appropriate GCR Volume (Stephenson et al., 2003). Only a brief summary of the most important Whin Sill features within the AONB is presented below.

The Holy Island Dyke forms the prominent ridge of Heugh Hill and Steel End, with Holy Island Castle in the distance standing on a further promontory formed of this rock.

Of particular importance are the Whin Sill dyke exposures on Holy Island. Most conspicuous of these is the rocky knoll upon which the Castle is sited, though other important outcrops are present at St Cuthbert's Isle, Heugh Hill and Jockey Scar. Notable features of the sill here include distinctive arcuate, ripple-like surfaces within lower parts of gas cavities, or vesicles, within the dolerite. These are almost identical to the so-called ropy textures found on the upper surfaces of modern lava flows in places such as Hawaii: the Hawaiin name 'pahoehoe' is used by geologists for this structure. The texture results from the flow of still molten magma beneath a solidified, or almost solidified, crust. Whereas Whin Sill magma was never erupted at the surface as lava, these remarkable structures give clear evidence that it was intruded at comparatively shallow depths (perhaps as little as a few tens of metres) beneath the surface. Slabs, or xenoliths, of Carboniferous rocks, intensely altered by the heat of the dolerite magma, are present in the Heugh Hill outcrop. Structures within the Whin Sill rocks on Holy Island have led to suggestions that the present day upper surface of the Holy Island Dyke lies close to the top of the intrusion. However, modern studies suggest that the intrusion here comprises a series of upward steps resulting in alternating dyke-like and sill-like intrusions.

At Harkess Rocks, north of Bamburgh, numerous fine examples of pahoehoe structures, like those at Holy Island may also be seen. The presence of pahoehoe structures in an intrusion of this sort is highly unusual and may be unique worldwide. Clear sections of cross-cutting relationships where the sill changes position from one horizon of Carboniferous rocks to another, are a feature of this section of coast.

Pahoehoe in Whin Sill dolerite exposed at Harkess Rocks, near Bamburgh.

The cliffs between Castle Point and Cullernose Point provide spectacular exposures of Whin Sill rocks. Features of particular interest here include numerous highly altered xenoliths of Carboniferous rocks engulfed within the sill (see the section on Metamorphic Rocks, below), and the presence of amygdales — large quartz and calcite-filled gas cavities within the dolerite (see the section on Minerals, below).

Vertical Whin Sill sea cliffs at Castle Point.

At Cushat Shiel, near Dunstanburgh Castle, the dark grey dolerite contains numerous veins and pods of pink felsitic rock up to about 5 cm across. These rocks give evidence of the changing composition of the Whin Sill magma during its final stages of crystallisation.

The cliffs of Cullernose point exhibit some of the finest columnar jointing seen within the Whin Sill of the AONB.

A few metres south of Cullernose Point, the vertical Cullernose Dyke occupies a fault cutting Carboniferous rocks. Xenoliths of broken rock (fault breccia) from the fault, included within the dolerite of the dyke, indicate that the dyke was intruded after initial formation of the fault.

The Farne Islands comprise a group of offshore islands composed almost entirely of Whin Sill dolerite.

A short distance west of the AONB, three other sites within the Whin Sill outcrop deserve brief mention. Longhoughton Quarry, just outside the AONB boundary, is designated as a GCR site for its fine exposures of contacts between the Whin Sill and the adjoining country rocks. Of particular interest are large rafts, or xenoliths, of Carboniferous rocks within the sill. Also of note is the relationship of the sill to the east-west trending Longhoughton Fault: it is clear that intrusion of the sill post-dated the main fault movement, though fracturing of the sill demonstrates evidence of later lateral movement along this fracture.

The ever-changing faces of Howick Quarry, a large working quarry that extracts Whin Sill dolerite for use as roadstone and crushed rock aggregate, offer opportunities to examine the spatial relationships of the rocks and associated structures as working proceeds. The quarry offers fine sections through freshly exposed dolerite and, depending upon the state of working, provides good sections through the lower contacts of the sill with the Carboniferous rocks.

In common with all working quarries, consideration of preservation of geological features exposed is an important geodiversity consideration when planning landscaping or reclamation of worked out sections.

Embleton Quarry, an abandoned quarry in the Whin Sill. Like many old quarries, this is now an important haven for wildlife.

Whin Sill in the landscape

Rocks of the Whin Sill give rise to some of the most distinctive and iconic landscapes within northern England, including the AONB. Hard and resistant Whin Sill dolerite provides the dramatic sites of Lindisfarne, Bamburgh and Dunstanburgh castles, and forms vertical sea cliffs at Castle Point and Cullernose Point. Inland, where free of superficial deposits, the Whin Sill typically forms conspicuous west-facing rocky cuestas or escarpments locally known as ‘heughs’, scared in many places by abandoned ‘whinstone’ quarries, notably in the Craster and Howick areas. The Farnes Islands are effectively a group of submerged cuestas with sheer west-facing cliffs and comparatively gentle north-east dipslopes.

Howick Scar, the conspicuous west-facing escarpment formed by weathering of the highly resistant Whin Sill dolerite.

Whin Sill and biodiversity

Where free of significant cover of superficial deposits, on dipslopes, scarp ledges and in some quarries, Whin Sill dolerite weathers to a base-rich, nutrient-poor, thin and drought-prone soil which supports a distinctive habitat known as Whin grassland. This typically consists of a short, grazed turf interspersed with bare patches and rock exposures, and is home to a substantial number of plant species that are both national and Northumberland rarities. Notable amongst these are the extensive spreads of spring squill (*Scilla verna*) found in the Dunstanburgh, Craster and Cullernose Point areas. The steep inland scarp slopes provide habitats for a range of interesting fern species. A number of the Whin Sill outcrops in the Craster and Cullernose Point areas support dense stands of gorse (*Ulex europaeus*). Also known as ‘whin’ bushes, it has been claimed that these may have been the origin of the name of the sill. Although primarily of botanic interest, Whin Sill outcrops in North Northumberland formerly supported populations of the Durham Argus butterfly (the northern English race *salmacis* of the northern brown argus *Aricia artaxerxes*) in association with its food plant, common rock rose (*Helianthemum nummularium*).

Whin grassland is a habitat that is almost unique to Northumberland and is the subject of a habitat action plan within the Northumberland Biodiversity Action Plan. Over half of Northumberland's Whin grassland lies within the AONB. Exposed surfaces of Whin Sill dolerite also locally provide important substrates for a variety of unique and scarce species of lower plants.

Seabird colony on a Whin Sill stack, the Farne Islands.

The vertical Whin Sill coastal cliffs of both the mainland and Farne Islands provide a wealth of nesting sites for a range of sea birds including guillemots (*Uria aalge*), kittiwakes (*Rissa tridactyla*), razorbills (*Alc torda*) etc. The more gently sloping Whin dipslopes of the Farne Islands support internationally important breeding sites for species such as terns and puffins (*Fratercula arctica*). The same gently dipping Whin Sill rocks of the Farne Islands are also internationally important breeding sites for the Atlantic grey seal (*Halichoerus grypus*).

Nothing is known of the impact of Whin Sill rocks on biodiversity in the submarine environments of the EMS.

Whin Sill quarrying

Comments on the past and present use of Whin Sill dolerite, or 'whinstone' are given in the section Mineral Extraction on page 50.

Wider significance of the Whin Sill

As noted previously, the intrusive igneous origin of the rocks of the Whin Sill were established in the mid 19th century; this sill then became the original, or 'type', sill of geological science. The term is used universally throughout the world by all geologists to describe concordant sheet-like igneous intrusions.

The Whin Sill rocks of the AONB have figured prominently in studies of the Whin Sill and have contributed greatly to the understanding of similar rocks elsewhere in the world.

Whin Sill rocks offshore within the EMS

The Holy Island Dyke extends seawards beyond its easternmost outcrop on Holy Island, at Scar Jockey, forming the small offshore reefs of Plough Rocks and Goldstone Rocks.

The Farne Islands archipelago comprises a cluster of small islands and isolated rocks, some exposed only at low tide, composed almost entirely of Whin Sill dolerite.

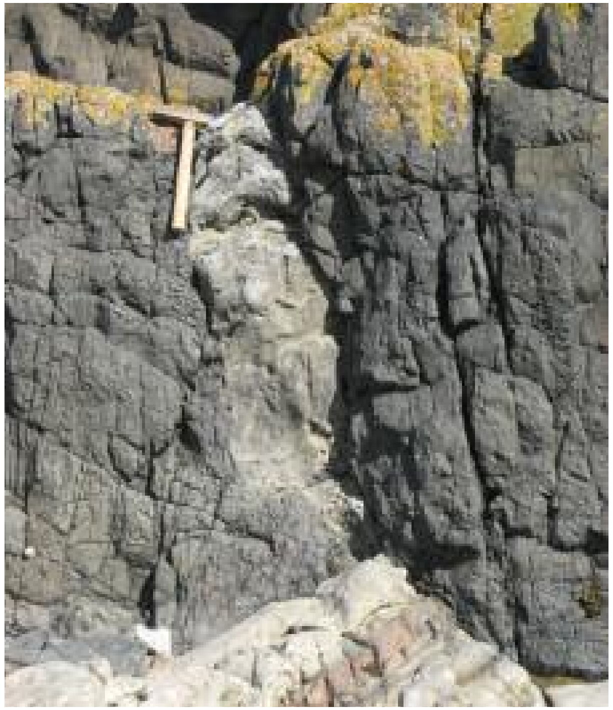
The 'solid' edition of the BGS 1:250 000 scale Farne Sheet depicts the main Whin Sill outcrop extending seawards from Bamburgh to approximately 20 kms east of Holy Island. In addition, several isolated dolerite dykes, almost certainly part of the Whin Sill swarm, are indicated in the offshore area between 2 and 8 kms north, and 18 kms east-north-east of Holy Island. Further south, on the same map, the Whin Sill dyke within the Alnwick Fault is traced offshore for approximately 10 kms and a further Whin Sill dyke, apparently not recognised onshore, is depicted within a sub-parallel fault for approximately 10 kms offshore from Alnmouth. No details are known of the nature of these offshore outcrops.

Metamorphic Rocks

Metamorphic rocks are rocks that have been altered from their original condition or composition by the effects of heat or pressure, or both. The mineral constituents of the original rock may have been recrystallised or, more commonly, as a result of complex chemical reactions, may have been altered into suites of new minerals.

Metamorphic rocks in the AONB/EMS

Within the AONB, metamorphic rocks are restricted to comparatively narrow belts of sedimentary rock adjacent to the contact of the Whin Sill intrusions and to the numerous rafts, or xenoliths, of similar rocks engulfed by the dolerite. This contact metamorphism, at temperatures up to around 1,100°C, was almost certainly accompanied locally by the introduction of chemically reactive fluids, a process known as metsomatism.



Blocks (xenoliths) of limestone, altered to marble by the heat of the intrusion, within the dolerite of the Holy Island Dyke, exposed on the beach at Heugh Hill, Holy Island.

Limestones have typically been recrystallised to form marbles. Good examples may be seen at Heugh Hill on Lindisfarne where the Acre Limestone, adjacent to the Holy Island Dyke, has been altered to a white marble, though with fossils of corals, brachiopods and other fossils still clearly recogniseable. At Longhoughton Quarry GCR Site, rafts of Great Limestone within the sill have been altered to coarse-grained white marble. Limestones with a high original content of clay and other impurities, have been altered to more complex rocks characterised by the presence of calcium silicate minerals such as garnet, vesuvianite (idocrase) and wollastonite. Such alteration reflects both the metamorphic effects of the extremely hot Whin Sill magma and the effects of metasomatism resulting from chemically reactive fluids within the magma. Good examples of these altered rocks occur within the xenoliths at Rumble Churn, near Dunstanburgh Castle and similar rocks have been observed adjacent to the main sill contact in parts of Howick Quarry.

Shales, both in contact with the sill's margins and as rafts or xenoliths within it, have been baked to a hard compact rock, commonly distinguished by a conspicuous spotted appearance, known as hornfels. Microscopic examination of these rocks has revealed the presence within them of metamorphic minerals such as biotite and andalusite.

Carboniferous shales altered to grey and purplish hornfels adjacent to the Holy Island Dyke, exposed on the beach south of Heugh Hill, Holy Island.

Sandstones have been recrystallised, though because they are typically composed mainly of quartz, generally contain no new minerals resulting from the alteration. However, metamorphic garnets have been reported from a sandstone raft near Dunstanburgh.

Coals are rarely seen in contact with the sill in the AONB, though at Castle Point, Embleton, a coal has been baked to cinder coal, a natural form of coke, adjacent to a Whin Sill dyke. Here, reaction between gases driven from the altering coal and the Whin Sill magma has altered the dolerite to a pale grey clay-rich rock known as 'White Whin' or 'White Trap'.

Ironstones are also rarely seen in contact with the sill and no published descriptions of their alteration have been found in the published literature. The finding by one of the authors (BY) in 2005 at Cragmill Quarry, Belford, of abundant metamorphic magnetite in clay ironstone nodules within a seatearth immediately beneath the lower contact of the sill, appears to be unique both in Northumberland and elsewhere adjacent to the Whin Sill.

Metamorphic rocks in the landscape

Within the AONB, the volume of metamorphic rocks is much too small to have any influence on landscape.

Metamorphic rocks and biodiversity

From their extremely small volume, most of the AONB's metamorphic rocks may reasonably be assumed to have little, if any, influence on biodiversity. However, it is possible that the crystalline texture, and possibly slightly altered chemistry, of contact-altered limestones may very locally give rise to soil or substrate conditions different from those of the unaltered parent limestone. Such alteration further south in Upper Teesdale, is an important factor in the development of soils and associated plant communities. Whereas nothing is known about any such influence in the AONB, its influence here must be of limited extent.

Economic use of metamorphic rocks

Whereas the volume of metamorphic rocks within the AONB is much too small to have attracted any commercial exploitation, the presence of rafts, or xenoliths, of metamorphosed Carboniferous rocks within the sill is likely to have given difficulties in 'whinstone' quarrying. Similarly, the deleterious effects of Whin Sill dolerite on coal seams is likely to have impacted adversely on some of the area's small coal workings.

Wider significance of the AONB's metamorphic rocks

Despite voluminous research on most aspect of the Whin Sill and its associated dykes throughout NE England, surprisingly little work has been undertaken on the associated metamorphic rocks or the alteration processes that formed them. The fine coastal exposures of these rocks within the AONB, especially the rafts or xenoliths within the sill, offer fine opportunities for such research.

Metamorphic rocks offshore within the EMS

Whereas contact altered rocks are no doubt present adjacent to the Whin Sill intrusions offshore, nothing is known of their nature or extent. As such rocks occupy a very restricted areas adjacent to the intrusions onshore, their offshore extent is also likely to be very small.

A large mass (xenolith) of white marble within Whin Sill dolerite in abandoned workings at Longhoughton Quarry in 1995. Although this section has been destroyed by subsequent working, quarries continue to expose important sections through features of this sort.

Quaternary Deposits and Landforms

The Quaternary Period spans the last 2.5 million years of geological history. Over much of northern Europe the beginning of this period was marked by a pronounced episode of global cooling which resulted in the formation of thick ice sheets, at times over 1 km thick, which covered much of Great Britain and Northern Europe. Throughout Quaternary times, the climate alternated between colder (glacial) and warmer (interglacial) stages. Several such glacial and interglacial stages are known to have affected Britain, though the majority of the deposits and landforms preserved today are believed to date from the most recent glacial period, known as the Devensian, which in Northumberland ended about 11,000 years ago. During glacial episodes, thick ice sheets scoured and modified the pre-existing landscape, creating vast amounts of glacial debris which was deposited beneath or on top of the ice sheets, or transported to adjoining areas by both the ice and meltwater.

Since the final melting of the last ice sheets, the most recent episode of geological time, in which we are living today, is known as the Holocene Epoch. Earth processes operating during that time, many of which are still active today, have produced a variety of geological materials.

Much of the present day form of the physical landscape, or geomorphology, of the AONB is a result of Earth processes that have affected the area during and after the last glacial period.

Quaternary deposits and landforms in the AONB

Over large areas the 'solid' Carboniferous and Whin Sill rocks of the AONB are concealed by an extensive mantle composed of a variety of unconsolidated 'drift' deposits formed during and since the most recent glacial episode, the Devensian.

A large volume of research has been undertaken on the complex pattern of ice flow and related processes during Devensian times in Northumberland. One of the most up-to-date reviews of these processes, and their effects on landscape formation, is that presented in the Geodiversity Audit and Action Plan for the nearby Northumberland National Park (Lawrence et al., 2007). From these studies it is clear that the AONB was heavily scoured by ice which originated mainly in southern Scotland, the Lake District and west and central Northumberland. As this flowed eastwards, it was deflected around the Cheviot massif which at that time supported its own rather static ice cap. On reaching the area of the present coast, this ice met a thick ice sheet, of Scandinavian origin, covering what is today the North Sea. This deflected the main ice stream towards the south or south-east, roughly parallel with the modern coastline.

A variety of deposits were formed by this ice and by meltwaters as the ice sheets finally decayed and disappeared around 11,000 years ago. The effects of comparatively rapid changes in sea level following this melting, resulting from a combination of relative sea level rises and 'rebound' of the land surface when relieved of the weight of ice, may be recognised in parts of the AONB.

Brief comments on the different Quaternary materials present within the AONB follow, accompanied by comments of their impact upon landscape, biodiversity etc.

Till (or boulder clay)

The 'drift' maps of the British Geological Survey depict extensive areas of the AONB mantled by spreads of boulder clay, though this term has been generally superseded today by the term till. Across much of northern England, including the AONB, till typically consists of a heterogeneous assortment of grey or brown silty or sandy clay in which occur rock fragments which range in size from gravel up to large boulders. The variety of rock fragments within the till give clear evidence of its source, and thus the direction of ice flow (see ***Erratics***, below).

Boulder clay, or till, exposed in cliffs near Longhoughton Steel. Blocks and pebbles of sandstone, limestone and Whin Sill dolerite in sandy clay matrix.

Detailed descriptions of the 'drift' geology in the Geological Survey memoirs, recognise two till sheets, separated by beds of sand and gravel and laminated clay. The lower clay is typically grey in colour and dominated by boulders of local rock types. The upper clay is commonly reddish purple with more far-travelled erratic blocks.

Important sections of till with associated sand and gravel deposits, exposed on the coast at Sandy Bay, are designated as a GCR site.

The till varies widely in thickness, though over much of the coast it generally does not exceed a few metres. Till-covered ground typically exhibits a smooth or gently undulating surface, commonly with damp, poorly-drained soils in hollows or low-lying areas.

At Kelsoe Hill, near Embleton, a bare Whin Sill dolerite crag is associated with a long 'tail' of till, on its south-eastern side, of till. Such 'crag and tail' landforms are comparatively common in glaciated areas with local outcrops of hard resistant rock. They indicate, as in this example, the direction of ice flow. The small crag of hard rock has protected the softer till on its lee side from the scouring effects of the over-riding ice.

Kelsoe Hill, near Embleton. A 'crag and tail' feature: an outcrop of resistant Whin Sill dolerite forms a low 'crag' on the north side of the hill (left in photograph) with a 'tail' of boulder clay, or till (right of photograph).

Erratics

These are glacially transported boulders or fragments of rock found within till, many of which, from their distinctive characteristics, may be traced back to their original bed-rock source. They therefore give clear evidence of the direction of ice flow. In addition to an abundance of locally derived sandstones, limestones and Whin Sill dolerite, erratics within the AONB include an abundance of greywacke sandstones from southern Scotland, and a variety of volcanic rocks and some blocks of granite from the Cheviots.

At a few places on the shore, small boulders of rocks that may be recognised as having a Scandinavian origin, may be found. These include a variety of gneisses and granitic rocks, together with rarer examples of striking rocks, known as 'rhomb porphyries'. These are fine-to-medium-grained varieties of the rock known as microsyenite from the Oslo district, characterised by the presence of conspicuous large rhomb-shaped feldspar crystals.

Whereas most erratics are of boulder size or smaller, north-east England is noted for the local presence of very large, or giant, erratics. Within the AONB a large erratic slab of coarse-grained sandstone, at least 56 m long, embedded in till, has been described from the low sea cliff at Emanuel Head at the north-east corner of Holy Island. A smaller slab of sandstone, about 18 m long and up to 1.5 m thick has been recorded from the sea cliff at Birling Carrs, north of Warkworth. These, and other very much larger erratic blocks, known from elsewhere in North East England, indicate very clearly the immense power of ice sheets to transport eroded material.

Erratic boulders of volcanic rocks from the Cheviot Hills on the beach at Coves Haven, Holy Island.

Glacial striae

As blocks of rock are ground together within a moving ice sheet, or as the ice sheet scours the rock floor over which it is moving, these rock fragments scratch deeply into one another. When exposed by weathering or quarrying, the bare rock surface (rockhead) beneath a sheet of till commonly exhibits deep grooves or striae, gouged out in this way. The striae are generally parallel, or nearly so, giving a clear indication of the direction of flow. Striae are best preserved on durable fine-grained rocks such as dolerite or limestone. Good examples are recorded on dolerite from the Farne Islands, near Cullernose Point and Littlemill Station, and on limestone at the old quarry west of Littlemill. Similar striations are extremely common on erratic boulders within till.

Sand and gravel

Beds of sand and gravel, of varying coarseness, lie within or between the beds of till. In addition, numerous, mostly small, patches of sand and gravel are mapped throughout the AONB, though with the greatest concentration in the Aln valley between Alnwick and Alnmouth. These deposits are the products of glacial meltwater, either during glaciation or during the final melting of the ice sheets.

Of particular importance is the long sinuous ridge of gravel, known as the Bradford Kame, which lies a short distance to the west of the AONB. The Bradford Kame Complex comprises a complicated assemblage of mounds and sinuous ridges composed of silt, sand and gravel. Perhaps the most obvious part of the complex is the very prominent ridges, known as eskers, which locally resemble large partially degraded railway embankments. These are conspicuous landscape features between Spindlestone and Pigdon Hill and between Newham and Preston, to the west of the AONB. The Bradford Kame Complex has long been the subject of detailed research and a variety of interpretations have been proposed to account for its origins. However, it seems likely that the main esker ridges formed as gravel-filled channels beneath or within an ice sheet: associated spreads of gravel, sand and silt may be the products of deltas deposited by meltwaters draining into glacial lakes. The importance of the Bradford Kame Complex in the understanding of Quaternary geology and processes in recognised in its designation as a GCR site.

Peat

Peat occupies small hollows, almost all of which were probably small lakes formed soon after the melting of the last ice sheets, at a few places immediately west of the AONB. The largest are those at Holburn Moss and Embleton Bog. At the former site, peat fills hollows in the hilly topography of the Fell Sandstone outcrop. The latter is the largest of a number of hollows in the Quaternary deposits including the gravels of the Bradford Kame.

Holburn Moss and Newham Fen are internationally important biodiversity sites. On the Farne Islands, thin patches of sandy maritime peat, too small to be depicted on the published 1:50 000 scale BGS map, rest on till and locally Whin Sill bedrock, and provide the main sites for puffin burrows.

Submerged forests

At numerous places on the British coast the remains of forest vegetation, below modern high tide levels, give clear evidence of significant post-glacial sea level changes. Within the AONB, very small remnants of such vegetation, including the remains of oak (*Quercus* sp.), alder (*Alnus glutinosa*) and hazel (*Corylus avellana*), some in original growth position, have been described from Howick Haven. Better known, and more extensive submerged forest remains are those at Druridge Bay, a short distance south of the AONB. Radio carbon dating of the organic remains from Druridge Bay reveals that forest growth and peat formation here occurred between 4700 and 2800 radiocarbon years before present.

The Bradford Kame The distinctive esker ridge, composed mainly of gravel, looking north at Goldenhill Farm, southwest of Bamburgh.

Alluvium and river terrace deposits

These include a great variety of sediments ranging from clays, through silts and sands to coarse gravels. Modern alluvial deposits flank many stream and river courses and are still accumulating, principally during flooding events. In addition, alluvial deposits occur in hollows formerly occupied by lakes or ponds, for example in the numerous small bogs associated with the hummocky topography adjacent to the Bradford Kame and similar deposits in the Spindlestone area. Accumulations of shell marl, a limy deposit formed principally of freshwater shell debris, are present in some of these bogs.

River terrace deposits are alluvial deposits that accumulated in response to higher base levels during Holocene times.

Raised and storm beach deposits

Raised beach deposits comprise sands and gravels, usually indistinguishable from modern beach deposits, but situated at elevations well above present sea level. They are the remnants of beaches developed during periods of higher relative sea level during the Holocene Epoch.

Beach deposits at elevations of approximately 1.5 to 1.8 metres above modern high tide level on both the seaward and landward side of the dunes at Ross Links, on parts of Holy Island, and at a handful of other rather isolated sites along the nearby coast, are depicted as raised beach deposits on the BGS 1:63 360 scale Holy Island sheet. However, the authors of the Holy Island memoir (Carruthers et al.,1927) express misgivings about the authenticity of these as true raised beach deposits, pointing out the significant absence of any vestiges of a clear rock cut shelf, characteristic of raised beaches, on any of the rocky exposures on the coast.

Modern research has identified a number of important raised beach and associated deposits on Holy Island which have been designated as GCR sites. Storm beaches are accumulations of similar beach deposits deposited by storms or exceptionally high tides.

Narrow belts of beach deposits at about 2.4 to 3.0 metres above present sea level in parts of Holy Island, notably west of Coves Haven, parts of the Snook and opposite the Sheldrake Pool may be examples of storm beach deposits. Prior to the formation of these deposits, it is likely that Holy Island comprised a group of three or more separate islets.

Modern beach deposits

As well as being iconic landscape features within the Northumberland coastal landscape, the modern beaches, and the materials of which they are composed, are important elements in the geodiversity of the AONB.

The BGS ‘drift’ maps of the AONB pre-date the modern practice of depicting and classifying these deposits.

Sands, gravel and accumulations of boulders, of both locally-derived rocks and blocks winnowed from the coastal till, or boulder, clay, comprise the modern beach deposits. These pass imperceptibly into finer-grained silt and clay deposits, described briefly below, as marine alluvium and saltmarsh deposits.

An unusual feature of certain beaches within the AONB, notably in Budle Bay, is the presence of ephemeral patches of sand composed predominantly of grains of minerals of high density. Most conspicuous are patches and streaks of vivid purple sand composed of up to 45% of garnet grains, though high concentrations of black grains of magnetite also occur either alone, or in association with garnet. These ‘heavy mineral’ sands have formed by the concentration by wave action, of grains weathered from some of the Carboniferous sandstones.

Another curious feature of certain beach sands is their so-called musical properties. At a number of locations around the coasts of Great Britain, some beach sands are known to emit an unusual whistling or singing sound when struck or walked on. It seems that uniformity of grain size within a narrow size range and roundness of the constituent grains causes sympathetic resonances to be set up so that the small vibrations caused by walking on the sand are amplified to an audible volume. Such musical sands have been reported from a number of places on the Northumberland coast, including at Bamburgh, Alnmouth and Dunstanburgh in the AONB, and also at Blyth, Druridge Bay, Seaton Sluice, Whitley Bay and Cullercoats.

The Ouse, Holy Island. Modern beach deposits composed of mud, silt and shingle.

Marine alluvium and saltmarsh deposits

These may be regarded as modern beach deposits composed of very fine sand, silt or clay. Extensive expanses of such deposits occur between Holy Island and the mainland where Holy Island Sands consists predominantly of firm sand. The silts and clays further south at Fenham Flats and in parts of Budle Bay, support distinctive saltmarsh habitats. Small areas of saltmarsh are also present near the mouths of the rivers Aln and Coquet.

Like modern beach deposits, marine alluvium and saltmarsh deposits are not separately depicted on published BGS 1:63 360 maps of the AONB.

Blown sand

Almost as iconic of the Northumberland coastal landscape as the dramatically sited castles, are the long stretches of coastal sand dunes. Indeed, the AONB includes some of the largest and finest of England's coastal dunes. Most extensive are those at the Snook and The Links on Holy Island, and Ross Links, north of Budle Bay. Long, though narrower, belts of dunes fringe considerable stretches of the coast between Bamburgh and Newton-by-the-Sea.

These consist of ridges, generally parallel to the coast and locally up to 26 m high, composed mainly of fine-grained sand. Calcium carbonate ($CaCO_3$) contents of up to 7 per cent in the dune sands reflect the abundance within them of finely comminuted shell debris. Dunes develop as sand is blown inland and deposited at the head of sandy beaches as a result of some obstruction to wind flow. As specialised plants such as lyme grass (*Leymus arenarius*), sand couch (*Elytrigia juncea*) and marram grass (*Ammophila arenaria*) become established, they help trap further sand and thus aid the development of major dune systems. With time, the dunes typically spread, or prograde, eastwards to cover earlier coastal deposits.

Coves Haven, Holy Island. An extensive area of dune sands.

Evidence of the abrasive effects of sand-laden winds may be seen at several places including Budle Point and Jenny Bell's Carr, where Whin Sill dolerite is polished and fluted by sand-blasting.

Sand dunes are geologically very recent additions to the AONB's geodiversity and are still actively growing. The remains of a medieval settlement, overwhelmed by encroaching sand dunes, have been found at Green Shiel on Holy Island and there is evidence that the Ross Links dunes may have grown since the 17th century. World War II coastal tank defences, buried by dune deposits, today lie some distance inland of the shoreline. Modern dating techniques, applied to sand grains, suggest that most of the AONB's dunes date from the so-called little Ice Age mainly between the 14th and 19th centuries.

Tsunami deposits

Borings through Holocene deposits near Cheswick have revealed a prominent layer of coarse-grained sand within a bed of peat. This has been interpreted as evidence of a large tsunami, or tidal wave, that struck the Northumberland coast between about 7,500 and 8,000 years ago. The tsunami is thought to have been triggered by a large sub-marine landslide off the Norwegian coast.

Post-glacial sea level changes

A number of the post-glacial deposits noted above, provide evidence of changing sea levels during the Holocene Epoch.

The immense weight of ice that developed across northern Britain during Quaternary times depressed the land surface. As this melted, and its weight was removed, the surface gradually rose, and continues to rise or rebound. As a result of this, a general tilting of the British land mass may be detected: northern Britain is known to be rising, whereas southern Britain is sinking. Northumberland lies close to the 'hinge' between these areas of relative movement. In consequence, it has been estimated that between about 4,000 and 3,000 years before present, north Northumberland has risen, relative to sea level, by about 2.5 metres whilst southern Northumberland has risen by only 0.5 metres.

Quaternary deposits in the landscape

The varied Earth processes and deposits produced by these during Quaternary times have exerted an extremely important influence on the landscape of the AONB.

Inland from the coast, the almost universal mantle of till, or boulder clay, gives rise to a generally subdued rolling topography, interrupted locally by small, craggy ice-scoured ridges and cuestas of Whin Sill dolerite and, in places rather less prominent ridges marking outcrops of Carboniferous limestones and sandstones.

Within the AONB, spreads of glacial sand and gravel are of limited extent, and give rise to the hilly country around Alnmouth and the lower reaches of the River Aln. The narrow elongate ridge, known as the Shorestone Kame, is a good, though rather small, example of this very distinctive type of landform. Much more conspicuous is the very much larger and important group of deposits known as the Bradford Kame Complex, which lies a short distance west of the AONB boundary. So prominent is this ridge that it provides a rare example of a geological deposit named on the 1:50 000 Ordnance Survey map.

Alluvial deposits and peat mark the sites of former lakes within the rather hummocky surface of till and sand and gravel deposits: these are especially common and well-developed on either side of the Bradford Kame complex.

Wide expanses of modern beach deposits, including the extensive tidal flats between Holy Island and the mainland, and long belts of sand dunes, all contribute to the highly distinctive landscape for which the AONB is renowned.

Quaternary deposits and biodiversity

Because Quaternary deposits mantle much of the 'solid' rock of the AONB, they provide the parent material for many of the soils and thus exert an extremely important influence on the vegetation. Throughout much of the area, soil type is much more dependent upon the nature and composition of these superficial materials rather than the underlying bedrock.

The variable nature of the till, or boulder clay, is reflected in a range of soil types, many of which have been further modified by centuries of agriculture.

Spreads of glacial sands and gravels, including those of the Bradford Kame Complex, support rather thin dry poor soils colonised by plant communities suited to such dry, and occasionally drought-prone, environments.

The internationally important ecosystems associated with sites such as Newham Fen, Embleton Bog and Holburn Moss, are dependent upon the alluvium and peaty deposits formed in these hollows in the mantle of Quaternary deposits.

Beach deposits are also host to a range of shoreline ecosystems, including specialised plant species and a wealth of invertebrate populations. The wide expanses of sandy, silty and muddy marine alluvium, including areas of saltmarsh, are home to a rich marine fauna and flora, as well as to a huge range of resident and migratory bird populations.

As well as being fine examples of modern wind-born sand deposits, the sand dunes of the AONB comprise another group of highly specialised ecosystems, characterised by a range of plant species, and associated invertebrates, unique to this environment. The comparatively high lime content (up to 7 per cent $CaCO_3$), due to the presence of finely comminuted shell debris, accounts for the local presence of a number of calcicolous plant species such as bloody cranesbill (*Geranium sanguineum*), viper's bugloss (*Echium vulgare*) and cowslip (*Primula veris*), within the dune flora.

The dunes, and particularly the 'dune slacks' or hollows between the dunes at the western end of Holy Island are rich in plant species, notably the marsh heleborine (*Epipactis palustris*) and the Lindisfarne Helleborine (*Epipactis sancta*), the latter recognised as a separate species only within the past few years.

*The Lindisfarne helleborine (*Elipactis sancta*) is a rare plant found in the dune slacks at the west end of Holy Island. (Photo: Jane Young)*

Economic use of Quaternary deposits within the AONB

Where comparatively free of abundant stones, clays from the extensive spreads of till have been worked for brick and tile making for local use. Small old clay pits for this purpose are recorded in the BGS memoirs in the Belford, Beal, Chathill, and Denwick areas. Old tile works are known to have worked till at Newham and Shilbottle.

The small deposits of glacial sand and gravel have been little used, though old workings are recorded from the Denwick area. Beach sand and dune sand have been extracted at several places along the coast, though extraction of these materials is today forbidden. No records have been found of any peat extraction from the small deposits scattered throughout the AONB and adjoining areas.

Boulders of a variety of rock types, extracted from the till, or picked as ‘clearance stones’ from fields, have been widely used in the construction of drystone walls, cottages and farm buildings.

Wider significance of the AONB’s Quaternary deposits

Within the AONB, and the adjoining areas, a number of sites and areas of Quaternary deposits have been recognised as of national or international scientific importance, as reflected by the designation of several places as GCR sites. The AONB’s Quaternary deposits provide important opportunities to gain further insights into the Earth processes responsible for their formation. In the light of likely future climate change, such studies are especially significant in understanding probable sea level changes and associated coastal processes.

Quaternary deposits offshore within the EMS

The broad character and distribution of Quaternary deposits within the EMS are depicted on BGS 1:250 000 scale Farne Sheet (Quaternary geology). Modern seabed sediments are depicted on BGS 1:250 000 scale Farne Sheet (Seabed sediments).

Geological Structures

Geological structures are features produced in rocks by distortions resulting from Earth movements. Structures may occur at any scale, ranging from faults of folds measurable in millimetres, and recognisable in small samples of rock, to huge structures measured in tens, hundreds or even thousands of metres, that affect whole regions of the Earth's surface. Similarly, geological structures may range form very simple to highly complex features, depending on the severity of the Earth movements involved in their formation. The recognition and interpretation of geological structures is fundamental to understanding the geology of an area and to deciphering the evolution of its rocks and landscape over geological time.

Geological structures in the AONB/EMS

In the AONB, as in all parts of the world, the overall geological structure may be appreciated by examination of geological maps. These clearly depict the configuration and three dimensional geometry of the component rock units.

Viewed on a regional scale, geological maps of north-east England reveal that the rocks of Northumberland comprise part of a thick succession of Carboniferous rocks that were subject to distortion soon after their deposition, during a major phase of Earth movements that affected much of northern Europe, and known as the Variscan Orogeny.

Such movements may bend or fold the rocks. Upward- closing, arch-like folds are called anticlines: downward-closing, or trough-like folds, are called synclines.

Immediately inland from the AONB, these movements produced a series of large folds, the most conspicuous of which on geological maps are the roughly north-south orientated Holborn Anticline which affects the Carboniferous rocks between the vicinity of Kyloe in the north, and Chillingham in the south, and the north-north-east–south-south-west trending Lemmington Anticline, to the west of Alnwick. The general form of these important structures is picked out in the landscape as a result of the weathering of rocks of differing resistance to erosion.

Within the area of the AONB, the geological structure is generally simpler. Here the Carboniferous rocks have been tilted gently towards the east or south-east. The broad pattern of distribution of these rocks reflects this overall dip, as progressively younger parts of the Carboniferous succession are encountered at outcrop as the coast is followed towards the south.

However, on a regional scale geological structure is rarely so simple. As in the remainder of Northumberland, the overall east or south-easterly dip is interrupted frequently by a number of faults within the component rock units. These are very conspicuous on the 1:50 000 scale geological maps of the AONB. Most common are roughly east-west trending faults, though other trends occur locally.

Faults are lines of fracturing in the rocks, on either side of which the rocks have been displaced relative to one another. Most commonly this relative movement has been mainly vertical: the rocks on the 'upthrow' side have been moved up relative to the rocks on the 'downthrow' side. Where this dislocation results from a stretching of the Earth's crust, the faults are known as normal faults. Most of the faults in the AONB are of this type. Where faulting resulted from a compression of the Earth's crust, reverse faults are formed. Where the relative movement and displacement along the fault was horizontal, rather than vertical, the fault is known as a transcurrent fault. A few of the faults within the AONB, e.g. the Longhoughton Fault, appear to be, at least in part, of this sort.

Whereas the major, large scale structures of the AONB are recognisable only by examination of geological maps, a number of smaller structures are beautifully exposed in the numerous fine sections through the Carboniferous rocks exposed on the coast.

It is both impossible and impractical in this text to comment on all such sections. However, the following examples are worthy of comment as giving valuable insights into this important aspect of the geodiversity of the AONB.

A spectacular asymmetrical anticlinal fold in the Eelwell Limestone is a conspicuous feature here at Saltpan Rocks, near Scremerston.

Dipping, or inclined, strata

In almost every exposure of Carboniferous rocks, the inclination or dip, of the beds is clearly visible.

Folds

The cliffs and foreshore at Saltpan Rocks at the northern end of Cocklawburn beach expose a number of extremely striking sharp ‘whale-back’ anticlinal folds within the Eelwell Limestone. Small folds of this sort, with amplitudes of a few metres, are locally common within Northumberland’s limestones, though those at Saltpan Rocks are perhaps the most spectacular. Similar folds may be seen at Newton Haven, south of Cullernose Point and at Howick Haven. Whereas they may have been formed by compression during the Variscan Orogeny, there is evidence that they could have formed during earlier phases of Earth movements during Carboniferous times, perhaps even whilst the sediments were still comparatively soft and uncompacted.

At Middle Skerrs, near Cocklawburn, the Sandbanks Limestone, is well exposed on the foreshore, where it has been folded into a gentle syncline.

A short distance north of the AONB, the foreshore north of Berwick harbour exposes spectacular larger folds, several tens of metres across, in the rocks of the Alston Formation.

Folds in the Acre Limestone at Snipe Point, Holy Island.

Faults

The Earth movements responsible for the dislocation, or faulting, of rocks, typically caused fracturing of the rocks for up to several metres on either side of the fault. As a result, these belts of broken rock tend to be weaker and more susceptible to weathering and erosion than the surrounding unbroken rocks. Faults therefore commonly give rise to escarpments or other topographic features where they juxtapose rocks of differing resistance to erosion, though the fault planes themselves are usually poorly, or rarely, exposed inland. Good sections may be exposed in quarries or, as in the AONB, in actively eroding coastal sections.

Small normal faults in rocks of the Alston Formation may be seen on the coast north of Cocklawburn beach. Other good sections through faults are exposed at Newton Haven, Cushat Steil and Howick Haven.

Perhaps the finest coastal exposure of a normal fault within the AONB is that of the Howick Fault which, together with associated smaller fractures, is exposed in the cliffs south of Cullernose Point. Here rocks of the Alston Formation on the north side are juxtaposed against Stainmore Formation rocks on the south.

The Howick Fault, exposed in the cliffs at Howick Bay. The Carboniferous rocks are here displaced approximately 200 metres to the south by the fault. The Acre Limestone forms the prominent ledge on the upthrow side of the fault (right of the photograph): shales and sandstones may be seen on the downthrow side (left of the photograph).

South of Longhoughton Steel, the Longhoughton Fault cuts sandstones of the Stainmore Formation. Roughly horizontal grooves, known as 'slickensides', may be seen on the fault plane here. These result from the grinding together of the rocks on either side of the fault during dislocation. Their horizontal orientation suggests that at least some of the fault displacement here was horizontal rather than vertical: the Longhoughton fault is thus an example of a transcurrent fault.

In a few places within the AONB, the belts of weakness along fault lines has provided channels for intrusion of Whin Sill magma. Thus, the Alnwick Fault at Boulmer is occupied by a narrow dyke of dolerite. Similar dykes occupy other faults south of Cullernose Point and near Embleton.

Geological structures in the landscape

The general easterly, or south-easterly dip of the Carboniferous rocks, together with the more or less concordant dip of the main Whin Sill intrusions, contributes to the cuesta-like form of many of the outcrops of these rocks, where not concealed by superficial, or drift, deposits. Similarly, this dip results in the sloping bench-like profiles of many of the rocks exposed on the foreshore throughout the AONB.

Faults which interrupt the continuity of 'solid' outcrops inland commonly find topographic expression in the abrupt ending of cuesta or scarp features.

Many of the bays along the coast coincide closely with the outcrop of one or more faults, where marine erosion has preferentially exploited the fractured or weakened rocks adjacent to these faults.

In the area immediately inland of the AONB, differential weathering of the Carboniferous rocks picks out the form of the Holborn and Lemmington anticlines.

Geological structures and biodiversity

Whereas the AONB's geological structures have little direct impact on biodiversity, the nature and disposition of the rocks resulting from these structures, clearly impact upon it.

Wider significance of the AONB's geological structures

The geological structures within the AONB give important insights into the geological evolution of northern Britain. The clear exposures of folds and faults on the coast provide unique opportunities to undertake detailed examinations and interpretations of these phenomena.

Geological structures offshore within the EMS

The 'solid' edition of the BGS 1:250 000 scale Farne Sheet depicts the main structural features within the offshore area adjacent to the AONB.

Conspicuous folds in the Sandbanks Limestone at Grey Mare Rock, Embleton Bay.

Fossils

Fossils are the preserved remains of animals or plants. Normally only the shells or skeletal parts of animals, or the most durable parts of plants survive as fossils; preservation of soft tissues, though known, is generally rare. The burrows, trails, tracks, footprints, worm casts or other feeding traces of many animals may also be preserved as trace fossils. Palaeontology is the study of ancient life, as revealed by fossils.

Fossils offer one of the most direct links between geo- and bio-diversity. In this context it is worth recalling that the vast majority of biological species that ever inhabited the Earth are extinct and reside within the fossil record. Assemblages of fossils, preserved in their original growth position enable reconstructions and interpretations of former ecosystems. In the AONB such assemblages may be found in some of the Carboniferous sedimentary rocks and in the peat and submerged forest deposits of Quaternary age.

Fossils, and fossil assemblages, give vital clues to the environmental conditions of deposition of the rocks in which they are preserved. In addition, study of fossils, enables the relative dating of the rocks in which they are found and allows important comparisons and correlations to be made with rocks of similar age worldwide.

Many of the techniques and principles employed by modern ecologists can also be applied to the investigation of associations of coexisting fossilised species, enabling the interpretation of ancient ecosystems. Palaeoecology is the term applied to this branch of palaeontology. Palaeontology and palaeoecology thus offer interesting links between geo- and biodiversity.

Fossils in the AONB/EMS

The Carboniferous rocks of the AONB are locally rich in fossils. In addition, some of the Quaternary sediments yield remains of contemporary animals and plants.

In consequence of their origins as accumulations of limey sediments, mostly formed by secretions of a variety of marine organisms, in the warm shallow tropical waters of the Carboniferous seas, the limestones of the AONB are locally rich in fossils of marine organisms. As most of these limestones are rather hard compact rocks, due to the effects of recrystallisation during their long geological history, fossils are usually rather inconspicuous in freshly broken rock. However, slight chemical and mineralogical differences in the composition of the fossils, compared to the surrounding limestone, typically results in these fossils becoming very much more conspicuous on weathered or sea-worn surfaces. The lime-rich shales that commonly overlie limestone beds are also locally rich in the fossilised remains of similar marine creatures.

Whereas close examination of almost any exposure of limestone will reveal traces of marine fossils, certain limestones at particular localities, offer good opportunities to see fine examples of a variety of Carboniferous creatures. Representative examples of fossils may be seen in the limestones at the following sites, though this is by no means an exhaustive listing.

South of Hud's Head, near Scremerston, the Woodend Limestone is rich in fossils of the colonial coral *Siphonodrendron* sp. (known as *Lithostrotion* sp. in older literature) together with sheets of the encrusting sponge *Chaetetes depressus* and examples of the solitary corals *Caninia* sp. and *Dibunophyllum* sp. At this site the two former fossilised organisms occur in their original growth position: the exposures of limestone here are a fine example of a Carboniferous sea floor, preserved in situ. It is therefore possible here to appreciate something of the long-extinct ecology, or palaeoecology, of Carboniferous times.

Boulder of Eelwell Limestone containing a conspicuous mass of the colonial coral Siphonodendron *sp. Beach at Saltpan Rocks, near Scremerston.*

Another good example of a Carboniferous ecosystem, preserved in situ, or nearly so, is a conspicuous band of the colonial coral *Lonsdaleia* sp., within the lowest metre of the Great Limestone at Beadnell Point. Well-preserved examples of the large brachiopod *Gigantoproductus* sp. also occur here.

At Cocklawburn beach, exposures of the Eelwell Limestone, and associated limey shales, contain an abundance of fragments of the stems of crinoids, or 'sea lillies'. This same limestone, at 'The Tumblers', north of Seahouses, is rich in fossils of other marine creatures.

So abundant are the disc-like segments, or 'ossicles' of crinoid stems, weathered from the in the lime-rich shales on some of the beaches of Holy Island, that they have long been known and collected as 'St Cuthbert's beads'.

The Oxford Limestone commonly contains roughly rounded nodules, typically around 2 cm across composed of the fossilised remains of the marine alga Girvanella: examples of these may be seen in the sea-worn exposures of the limestone of Monks House Rocks, north of Seahouses.

At the Near and Middle Skerrs, near Cocklawburn, the Sandbanks Limestone is locally rich in fossils of a variety of brachiopods and solitary corals.

Well-preserved fossils of bivalves, crinoids and brachiopods are locally abundant in the shales above the Sandbanks Limestone at Cocklawburn.

The Acre Limestone, and its overlying shales, formerly exposed near Dunstan village, were notably fossiliferous, with abundant crinoids, brachiopods, molluscs and fragments of trilobites.

Exposures of the Sugar Sands Limestone at Sugar Sands Bay, contain numerous fossils, prominent amongst which are good examples of the brachiopod *Gigantoproductus* sp.

The Lickar Limestone, exposed on the shore at Howick, is notable for the variety and fine preservation of its fossils of marine creatures.

As most of the sandstones originated as sands deposited in river channels or deltaic environments, they do not offer ideal conditions for the preservation of fossils. However, fragments of plant may locally be seen in some of these rocks. Most common are fossilised casts of roots of the lush Carboniferous tropical vegetation, known as 'stigmaria' or 'stigmarian roots'. Fragments of plant stems may also be seen locally. More diffuse traces of former rootlet systems may be seen in the beds, known as seatearths, that immediately underlie coal seams. Most of the plant fragments and traces found in the AONB's rocks are too poorly preserved to identify even at the generic level.

In addition to the fossilised remains of individual creatures, evidence of their former presence may be preserved as 'trace fossils'. These include fossilised remnants of the burrows or trails made in the originally soft sediment by a variety of invertebrates, including molluscs and worms. Numerous examples of these may be seen in many coastal exposures of siltstones and sandstones. Distinctive roughly concentric patterns of shallow grooves are conspicuous on some bedding plane surfaces. Known as *Zoophycos*, these are believed to be the feeding traces created by some form of extinct worm-like creature. Good examples may be seen on bedding planes of the Eelwell Limestone at Cocklawburn beach, on the Sandbanks Limestone at Middle Skerr and near Beadnell Point.

The distinctive trace fossil Zoophycos on the bedding surface of limestone in a loose block at Coves Haven Holy Island.

Most celebrated of the AONB's trace fossils are the fossilised footprints of a Carboniferous amphibian, preserved on a sandstone bedding plane surface to the south of Howick Haven. Unfortunately, these remarkable trace fossils are no longer clearly visible.

Much more recent fossil remains include the plant fragments, including tree stumps in their original growth position, branches and hazel nuts, found within the submerged forest deposits at Howick and in Druridge Bay.

Fossilised pollen grains, extracted from peat deposits on the Farne Islands, reveals that apart from a few elder bushes, the islands have almost certainly been treeless through Holocene times.

Minerals

A mineral is defined as "A substance having a definite, but not fixed, chemical composition and atomic structure and normally formed by the inorganic processes of nature". Individual minerals are referred to as species. The study of minerals is called mineralogy. As rocks are composed of different minerals in varying proportions, minerals may be regarded as the essential components of those rocks. Outside of the Earth sciences, the term 'mineral' is commonly used to denote any natural product obtained from the Earth. Thus, although it is common to regard coal, oil, gas, limestone, 'whinstone', peat etc as mineral products, they do not fulfil the strict definition of a mineral. This section of the document is concerned with minerals, as they are defined above.

Minerals within the AONB/EMS

Individual mineral species are the essential components of rocks. Brief comments on the mineralogical composition of the AONB's rocks and sediments are given in appropriate sections of this document and will not be discussed further here. Minerals may also occur alone, or in associations, in a variety of other geological environments. Within the AONB, these occurrences include mineral veins – narrow vertical bodies that cut pre-existing rocks as cavity fillings within the Whin Sill, and as pebbles on modern beaches. Each of these will be reviewed briefly below:

Mineral veins

Because of their geological setting, the rocks of the AONB lie well beyond the concentrations of mineral veins that comprise important elements in the geodiversity of south Northumberland, most notably in the Northern Pennines and Tyne Gap. However, a number of veins are present, though they are little known.

Galena (PbS), the main ore of lead, has been recorded from small veins found in a small coal working near Rock Hall, on the foreshore at Beadnell, on the coast at Ellwick, on the east side of Holy Island, in the Lowick area, in the fault exposed in the cliffs at Howick, associated with marcasite at Little Houghton, and in underground workings in Shilbottle Colliery, a little way to the south of the AONB. Apart from unsuccessful attempts to work the first two of these, no attempts at exploitation are known. None is known to be exposed today and the writers are unaware of the existence of any specimens of ore from these occurrences.

Near Harkess Rocks, the Whin Sill contains a few veins, up to a few centimetres wide, containing baryte, calcite and pyrite. Narrow veins of calcite, locally accompanied by dolomite, occur in some of the limestones, for example at Salt Pan Rocks and at Grey Mare Rocks.

At Cragmill Quarry quartz veins up to about 2 cm wide have been noted, with sprays of dark brown goethite crystals, apparently associated with the metamorphism of the ironstone nodules, described previously in the section on Metamorphic rocks.

Cavity fillings

Gas cavities, or vesicles, within the Whin Sill, mentioned above, are commonly partially or wholly filled with minerals and are then referred to as amygdales. Most common of the introduced minerals are calcite and quartz. Well-formed colourless crystals of quartz have long been known as 'Dunstanburgh diamonds'. Also present are quartz crystals of a purple colour, giving the variety known as 'amethyst'.

Calcite fills amygdales in the Whin Sill dolerite at Harkess Rocks, near Bamburgh.

Nodules within Shales

The unusual occurrence of galena, accompanied by the zinc sulphide mineral sphalerite ((Zn,Fe)S), of sedimentary origin, in nodules scattered through Carboniferous shales, has been noted in the section on Carboniferous rocks.

Weathering products

Vivid yellow crystalline crusts of iron sulphate minerals including copiapite, resulting from the weathering of pyrite–rich coal, are locally conspicuous on weathered exposures of some coal seams, for example in Howick Bay and at Salt Pan Rocks.

Bright yellow coatings of the iron sulphate mineral copiapite, formed by alteration of the mineral pyrite, may be seen in dry weather on surfaces of coal seams as here at Howick Bay.

Beach pebbles

The local boulder clay, or till, commonly contains erratic blocks of rocks derived from the Cheviots. Small, but often beautifully patterned, agates from the Cheviot lavas, winnowed by the sea from these deposits, are locally common on some beaches.

Small agates collected from the shingle at Cocklawburn Beach. Agates are locally common in the lavas of the Cheviot Hills and may be found on many of Northumberland's beaches whence they have been carried by ice sheets during the last glacial period.

Economic use of minerals

Despite brief records of attempts to explore the economic potential of lead ore at Rock Hall and Beadnell foreshore, there has never been commercial working of these or any other lead ore occurrences in and adjacent to the AONB.

Wider significance of the AONB's minerals

Irrespective of their uneconomic scale, the scattered occurrences of lead ore have hitherto attracted surprisingly little scientific interest. With modern analytical techniques, they may be of interest in offering useful insights into the role of the thick succession of Carboniferous sediments of the Northumberland-Solway trough as a potential source of ore-forming fluids, in the mineralization of the Northern Pennine Orefield.

Mineral Extraction

It is clear from the definition of geodiversity, quoted in the introduction to this document, that an area's geodiversity embraces not only the geological materials and the processes that formed them, but the materials and products that have been extracted as raw materials.

A variety of mineral products has been worked in the AONB in the past. As the extraction of most of these has left some legacy on today's landscape and environment, these must be considered as vital elements within the AONB's geodiversity. Although no form of mineral extraction is active within the AONB today, two substantial quarries are still operating within a few kilometres of its western boundary.

Brief comments follow on the mineral products known to have been worked within the AONB, or within the immediately adjoining areas.

Coal

Numerous coal seams occur within the Carboniferous rocks of the AONB. Whereas many of these are too thin or of too poor quality to have been of economic interest, a significant number have been worked. Within the AONB most of the workings were comparatively small and supplied local needs, mainly for domestic use and for lime burning. However, a few seams in the areas immediately adjoining the AONB were worked on a more substantial scale, in some instances supplying coal to a wide area of Northumberland and beyond.

The greatest concentration of coal seams in this part of Northumberland occurs within the succession of rocks formerly known as the Scremerston Coal Group, now included within the Tyne Limestone Formation. As might be expected, these rocks take their name from the village of Scremerston, a short distance north of the AONB. Several seams crop out on the coast here where they were originally discovered and probably first worked. As the most easily won coal was exhausted from these outcrops, the seams were followed inland from a number of underground collieries. The partially collapsed remains of old mine entrances and drainage adits can be seen near Hud's Head.

Further south, a number of seams were worked from shallow shafts on Holy Island, in the Kyloe, Fenwick, Belford, Seahouses, Beadnell, Embleton and Howick areas. These seams were locally up to 0.6 metres thick, though many were much thinner. The positions of many of the shafts are indicated on the 1:50 000 scale geological maps. A number of seams are still exposed on the shore and in the cliffs around Sea Houses and Beadnell.

The most significant coal deposits within the neighbourhood of the AONB, and the most recently worked, are those of the Shilbottle seam within the rocks of the Carboniferous Alston Formation. This seam was locally up to 0.7 metres thick. Underground workings in this seam approach the AONB near Lesbury and High Buston. The most recent workings here, at Shilbottle Colliery, closed in 1982.

The Acre Coal, a thin coal seam exposed in the cliffs at Saltpan Rocks, near Scremerston.

Limestone

Numerous beds of limestone occur within the Carboniferous rocks of the AONB. Whereas many of these are comparatively thin, commonly less than 2.5 metres thick, several were thicker and were exploited on a considerable scale for the making of burnt lime, or quick lime. This had two main uses locally. Firstly, when hydrated with water, to produce slaked or hydrated lime, it was used as a soil improver to sweeten acidic soils. Secondly, substantial quantities of lime were used in making lime mortar, an essential building material before the widespread use of Portland cement.

Many of the AONB's limestones have been worked in small quarries, often for small scale local use. Larger quarries, with attached limekilns, were worked at Cocklawburn, Holy Island, Seahouses, Beadnell and Littlemill. Ruined limekilns remain at many of these sites, adjacent to the long-abandoned quarries. At some of these locations, e.g. Cocklawburn and Littlemill, burnt lime was transported from the area via the main east coast railway. The kilns on the harbourside at Beadnell served an important coastal trade in burnt lime.

Old flooded quarries in the Eelwell Limestone at Seahouses Golf Course.

Sandstone

Sandstones comprise a substantial proportion of the AONB's succession of Carboniferous rocks. Many of these have been employed as local building stones, though the high quality sandstone formerly quarried at Denwick, was employed widely across northern England and southern Scotland.

Beadnell limekilns, once the centre of an important coastal trade in lime.

'Whinstone'

Whin Sill dolerite, more commonly known in Northumberland as 'whinstone', provides an excellent roadstone and has been quarried from many of its outcrops in the AONB. The industry reached its peak production during the 19th and early 20th centuries, producing both chippings and setts. Quarries which were worked around Bamburgh, Embleton, Craster and Howick remain conspicuous landscape features today. At Craster 'whinstone' chippings, produced in the quarry which is now the village car park, were carried by aerial ropeway to large hoppers on the pier from which they were loaded into steamers: the foundations of these hoppers remain prominent features of Craster harbour today. None of the quarries within the AONB is active today, though large quarries are still working at Belford and Howick a short distance to the west.

The main car park at Craster is sited within the former whinstone quarry, the faces of which are now seriously overgrown.

Whereas Whin Sill dolerite has not been widely employed as a building stone elsewhere in Northumberland, it has been much used in Bamburgh, Craster and Embleton where it gives a distinctive character to the cottages built from it.

Craster Harbour. The foundations of the silo on the pier from which whinstone chippings from the nearby quarry were loaded onto coastal ships.

Iron ore

Rounded nodules of clay ironstone, composed mainly of fine-grained concentrations of the iron carbonate mineral siderite ($FeCO_3$), are common in several of the shale units within the AONB's Carboniferous rocks. Large examples of these, from shales above the Acre Limestone on Holy Island, were collected from the beaches and exported to Scotland as iron ores in the late 18th century.

Clay ironstone nodules from shales above the Acre Limestone at Coves Haven, Holy Island. These were extracted here in the late 18th century and taken by sea to furnaces in Scotland.

Fragments of iron slag, found on the shore at Cocklawburn, suggest that some early small-scale iron smelting may have taken place here, no doubt exploiting ironstone nodules from the Carboniferous shales exposed nearby.

Lead ore

The occurrence of narrow veins of the lead ore mineral, galena, in and near the AONB has been mentioned above. Apart from unsuccessful attempts to work the veins at Rock Hall and Beadnell no attempts at exploitation are known.

Sand and gravel

The small deposits of glacial sand and gravel have been little used, though old workings are recorded from the Denwick area. Small quantities of sand have been dug from time to time from beaches and sand dunes.

Brick clay

Where comparatively free of abundant stones, clays from the extensive spreads of till have been worked for brick and tile making for local use. Small old clay pits for this purpose are recorded in the BGS memoirs in the Belford, Beal, Chathill, and Denwick areas. Old tile works are known to have worked till at Newham and Shilbottle.

Salt

Sea salt is known to have been produced at Saltpan Rocks, near Cocklawburn by the evaporation of sea water in large iron pans heated by local coal.

Mineral extraction in the landscape

Mineral working, whether by mining or quarrying, inevitably has an impact on landscape which, in some instances may survive long after the closure of the industry. The most conspicuous legacy of mineral working within the AONB is the scatter of old quarries, in many of the outcrops of limestone and 'whinstone'. Whereas most of these are very small, a few larger workings are also present. Such abandoned quarries may justly be regarded as essential and distinguishing features of the modern landscape and clearly reflect an important aspect of the local geodiversity. The substantial 'whinstone' quarry at Craster, now the site of the main village car park, and the remains of the loading facility on the harbour wall, are important in giving character to the village. Similarly, the limestone quarries, their spoil heaps and associated limekilns at Cocklawburn, Holy Island and Beadnell are also essential local landscape features.

The extraction of sandstone from coastal exposures has left evidence of former quarrying in the cliffs at Rumbling Kern and at Birling Carrs. Traces of quarrymen's chisel marks may still be seen on the rock faces at the latter site.

Although coal was widely worked throughout parts of the AONB, unlike the main coalfield further south in Northumberland, there are today few visible remains of the industry. Small depressions which mark the sites of former colliery shafts near Seahouses golf course, and the conspicuous stone-built tower at the Snook, Holy Island, which is supposed to cover a disused coal mine shaft, are perhaps the most obvious remains of the AONB's former coal industry. In the area immediately beyond the AONB, former coal mine drainage adits may be seen in the cliffs near Scemerston. Inland from here, and further south around Shilbottle, remains of colliery spoil heaps and a handful of colliery buildings may still be seen.

Mineral extraction and biodiversity

Whereas mineral extraction is commonly portrayed in a negative light, it is important to recognise that many former mineral workings may be important havens of biodiversity. Quarry faces exactly mimic natural rock faces, and when abandoned, may become important habits for a variety of plant species as well as nesting and roosting sites for birds and bats. Even before abandonment, it is not uncommon in many working quarries, to find that inaccessible faces, isolated from close human interference, are selected as nesting sites by a range of birds of prey.

Quarry floors similarly may provide important habits for a range of plant species, together with dependent invertebrate, as well as reptiles, amphibians and small mammals. The long-abandoned and partially flooded limestone quarry at Seahouses is today an important brackish water habit that is home to such marsh plants as reedmace (*Typha latifolia*), water crowfoot (*Ranunculus baudotii*) and northern marsh orchid (*Dactylorhiza purpurella*).

Quarry spoil heaps may offer excellent habitats for interesting and perhaps rare plant species. Of particular importance within the AONB are the spoil heaps associated with former limestone quarries at Cocklawburn where thin lime-rich soils support a number of typical limestone grassland plants such as bloody cranesbill (*Geranium sanguineum*), viper's bugloss (*Echium vulgare*), common restharrow (*Ononis repens*) and cowslip (*Primula veris*).

A variety of characteristic plants colonising limestone-rich spoil at the old quarries at Cocklawburn.

Old limekilns may offer an abundance of roosting and breeding sites for a variety of bat species.

Environmental impacts of mineral extraction

Within the AONB the environmental impacts of limestone, 'whinstone' and sandstone quarrying have been their visual impact on landscape and their influence on biodiversity, as discussed above.

Coal is the only mineral product known to have been worked underground both in the AONB and immediately adjoining areas. As in all underground mining, there is potential for significant environmental impact. Perhaps most obvious is the possibility of surface collapse through subsidence of old workings. Undoubted evidence of problems resulting from such subsidence have not been found within the AONB, though collapse of underground workings is known in the Scremerston and Shilbottle areas.

The abandonment of underground workings, and the cessation of pumping of groundwater, typically results in the flooding of abandoned workings that lie beneath the water table. In certain circumstances this mine water may discharge to the surface in an uncontrolled manner. Such mine water is commonly heavily contaminated with high concentrations of iron, and in some cases manganese and aluminium salts all of which are extremely damaging to land or water courses into which they may discharge. We have been unable to find reliable records of any such discharges within the AONB. However, serious damage to property in Spittal, a short distance north of the AONB, has occurred within the past ten years as a result of the sudden discharge of contaminated mine water from abandoned underground workings in the Scremerston coal seams. Controlled pumping of mine water, and its treatment prior to safe discharge into water courses, has been established to prevent, or minimise, environmental damage from the extensive workings in the Shilbottle coal, in the area immediately south of the AONB.

Wider significance of mineral extraction within the AONB

Whereas many of the locally worked mineral products were used within, or very close to, the AONB, several commodities were exported far beyond the area. Limestone, and more especially quicklime and slaked lime, from several sites was exported from the area, both by road, and by sea, supplying markets well beyond the AONB. Coal was also widely exported for use beyond the AONB. Similarly, sandstone from quarries within, or very close to, the AONB was employed widely across northern England and southern Scotland as a building stone. A considerable coastal trade in 'whinstone' chippings once flourished from Craster. Small amounts of iron ore, picked from the beaches of Holy Island are known to have been exported to furnaces in Scotland.

Building Stones and the Built Environment

The built environment includes castles, houses, farms, churches, graveyards, schools and other public buildings, harbours, road and railway bridges and viaducts, and drystone walls.

Built structures of all sorts are essential elements in the landscape. Where constructed wholly or partly of locally-sourced materials, these buildings clearly reflect the local geology and can thus be regarded as key factors in the local geodiversity.

Built structures offer readily accessible opportunities to demonstrate a range of rock types, both from the local area and, where imported materials have been employed, from a range of more exotic locations. Building materials aid appreciation of the importance of the Earth's resources through understanding the properties and limitations of those materials, and the ways their uses may have changed over the centuries. They thus have significant educational potential.

Building stones within the AONB

Natural stone is the predominate material employed in most of the older built structures within the AONB. Traditional vernacular architecture depended, both for its character, and for its raw materials, on the availability of locally sourced stone. Until the late 20th century more costly materials, imported from beyond the area, were generally only employed for specialised purposes, such as the construction of prominent domestic or public structures.

The AONB contains, within its boundaries, and in the immediately adjoining areas, a variety of types of stone, many of which figure prominently in the local built environment.

The main rock types employed are outlined below:

Sandstone

As in much of rural Northumberland, sandstone imparts a distinctive character to a large proportion of the buildings throughout the AONB.

Sandstones comprise a substantial proportion of the AONB's succession of Carboniferous rocks. Almost any reasonably durable sandstone may be suitable for use in vernacular architecture, where cost and ease of availability have generally been of greater importance than aesthetic or other considerations. Thus, many of the local sandstones have been worked, commonly on a very small scale, for limited local use, perhaps solely to supply stone for a single building. As few of the local Carboniferous sandstones exhibit individual distinguishing features, determining the provenance of the stone used in any single structure is commonly difficult or impossible. However, in a few instances, notably with major structures, characteristics of the stone, perhaps combined with documentary records, may be sufficient to identify the source with confidence. For example, it is known that Haggerstone Castle was built from stone quarried at Collar Heugh, west of the Kyloe Hills, Dunstanburgh Castle is largely built of the locally sourced Dunstanburgh Sandstone, and there are grounds for believing that Holy Island Priory was constructed from stone quarried, or collected from the beach, at Cheswick.

Many of the smaller sandstone quarries throughout the AONB are today completely obscured or overgrown. However, the remains of larger quarries, where stone of much higher quality, suitable for export beyond the area, was worked, may still be seen at Denwick and in the sea cliffs at Rumbling Kern.

The Denwick Quarries were especially important and yielded by far the best quality sandstone within the area. Large tonnages of Denwick stone were used in prominent buildings over a wide area of northern England and southern Scotland, including the Hancock Museum, Newcastle; Trinity House, Newcastle; and the former Post Office in Sunderland.

St Aidan's Church, Bamburgh is built largely of locally worked Carboniferous sandstone, with Carboniferous sandstone slabs roof tiles (of unknown provenance). Memorials in churchyards such as this commonly employ a variety of rock types.

Limestone

Local limestone has been little used as a building stone, no doubt because of the ready availability of more abundant sandstone and the greater value of limestone as a raw material in the making of quicklime.

‘Whinstone’

Because of its hard, intractable nature, the dolerite of the Whin Sill is a difficult rock to work and in most parts of Northumberland is not widely used as a building stone. However, close to its outcrops at Bamburgh and Craster, dolerite has been much used in vernacular architecture. ‘Whinstone’ cottages contribute greatly to the character of Craster’s built environment and are also conspicuous in Bamburgh, Embleton and elsewhere in the AONB.

Cottages at Craster are built mainly of locally quarried undressed ‘whinstone’ rubble from the Whin Sill. Quoins, lintels and window casings are mainly of Carboniferous sandstone of unknown provenance. The roofs are of Welsh slate.

Clearance stones

Blocks and boulders cleared from fields have commonly been a ready source of building material, mainly for stone walls, cottages and farm buildings. As many of these ‘clearance stones’ are boulders weathered from glacial deposits, mainly till, a variety of rock types, including many introduced from outwith the AONB, may be present. Such clearance stones are usually readily detectable in structures due to the variety of rock types and their commonly rounded outlines.

Clay tiles

Red pan tile roofs, contrasting with rough stone walls, are locally distinctive features. These were produced from locally won, comparatively stone-free clays within the till. The use of clay tiles reflects the general scarcity within the AONB and adjoining areas of other local roofing materials such as sandstones capable of being split to give thin roofing slabs.

Brick

Whereas brick, made by firing locally sourced clays, mainly from the till, have been used locally, their use in pre-20th century buildings is not widespread. However, within the past century, the increasing cost of natural stone, combined with the closure of most of the local stone quarries, has resulted in a dramatic rise in the use of brick and other synthetic block materials, imported from outside of the AONB.

Slate

Dark grey or blue-grey slate, mainly from north Wales, became a popular and widespread roofing material during the 19th century as the railways provided a ready means of efficient and cheap transport. Slate roofs are conspicuous in many places within the AONB.

Building stones and biodiversity

The rocks and mortar used in buildings provide substrates for a variety of lower plants, including mosses and lichens. In addition, buildings fulfil many of the roles of quarry faces and natural cliffs, offering shelter and nesting sites for bats, birds and a variety of small mammals.

Lindisfarne Priory is built mainly of Carboniferous sandstone, perhaps obtained from the Cheswick area. Locally sourced stone, including Whin Sill dolerite, may be seen in the exposed rubble cores of many of the walls.

Action Plan

This action plan is intended to guide the work of Northumberland Coast AONB and European Marine Site teams and their partners. It is divided into four sections:

- Understanding more about our geodiversity (pink)
- Conserving our geodiversity (yellow)
- Interpreting our geodiversity (green)
- Education and lifelong learning about our geodiversity (blue)

These actions were derived from the work of auditing and assessing the geodiversity of the Northumberland Coast and assessing the opportunities for understanding, conserving and celebrating it. It is not an exhaustive list of actions – other ideas may come forward during the life of this plan and these should be accommodated where time and funds allow.

Abbreviations used in this Action Plan

AONB/EMS	Northumberland Coast AONB and European Marine Site teams
BGS	British Geological Survey
EA	Environment Agency
Mus	Museums
NCC	Northumberland County Council
NE	Natural England
NEGF	North East Geodiversity Forum
NNHS	Northumberland Natural History Society
NT	National Trust
NWT	Northumberland Wildlife Trust
UNIs	Universities

Objective	Action	Partners	Timescale
1 To ensure that sites and features of Earth heritage importance are protected from adverse impacts of development.	1 Assess other sites identified in this audit and action plan against the criteria and seek the designation of any that qualify.	**AONB/EMS**, NWT	2010–11

Objective
Something we want to achieve by 2014.

Action
Work towards meeting the objective.

Partners
Not an exclusive list of those involved, but those which are central to implementing the action. Lead in bold.

Timescale
When will it be done by (sometimes 'how many' per year or during the life of the plan).

Understanding more about our geodiversity

Objective	Action	Partners	Timescale
1 To acquire improved data and support new research about the geodiversity of the coast.	1 Establish and maintain a GIS record of sites/ features and their management and interpretation.	AONB/EMS	2009
	2 Establish links with academic institutions and support studies linked to the research priorities through staff time, data and project funding.	**AONB/EMS**, UNIs, BGS, Mus	2009–2014
	3 Acquire, maintain and update a set of maps, books, reports and studies on the geodiversity of the coast.	AONB/EMS	2009–2014
	4 Establish a set of geodiversity research priorities for the coast.	**AONB/EMS**, UNIs, BGS, Mus	2010

Conserving our geodiversity

Objective	Action	Partners	Timescale
2 To ensure that sites and features of Earth heritage importance are protected from adverse impacts of development.	1 Support the production of new and more robust criteria for Local Geodiversity Sites.	NEGF	2010
	2 Assess Local Geodiversity Sites against the new criteria, ensuring input from qualified geologists.	**NWT**, NE, AONB/EMS	2010–2011
	3 Assess other sites identified in this audit and action plan against the criteria and seek the designation of any that qualify, ensuring input from qualified geologists.	**AONB/EMS**, NWT, NE	2010–2011
	4 Adopt the revised list of second tier sites which arises from the new criteria and assessment.	NCC	2011
	5 Consult the list of Local Geodiversity Sites in relation to new development proposals and take steps protect sites as necessary.	NCC, EA	2009–2014
	6 Incorporate polices in the Northumberland Local Development Framework which protect second tier geological sites from adverse impacts of development.	NCC	2012
	7 Provide opportunities for local people and groups to adopt suitable sites, to ensure they remain accessible and litter-free.	**NCC**, RIGS	2009–2014
	8 Provide information for landowners and managers on the location and importance of Earth science features on land which they own or control.	AONB/EMS	2009

Introduction

Geology of the Coast

Geodiversity Audit

Action Plan

Reference

Conserving our geodiversity

Objective	Action	Partners	Timescale
3 To achieve favourable or unfavourable recovering condition for geological SSSIs.	1 Assess the condition of geological SSSIs and produce management prescriptions where required.	NE	2010
	2 Secure and implement revised management agreements for SSSIs shown by condition monitoring to require them.	NE	2010
4 To conserve the geological interest of individual sites and features.	1 Clear some of the tree cover which is gradually shielding from view the quarry faces at Craster car park.	**AONB/EMS**, NCC, NE, NWT	2010
	2 Record and conserve important geological features in quarries alongside commercial activity and encourage enhancement of those features where possible.	AONB/EMS, Operators	2010
	3 Encourage the establishment of new sites and features of geodiversity value. This should be a feature of any review of restoration plans for quarries.	**NCC**, Quarry Operators, AONB/EMS	2009–2014
	4 Clear faces and Embleton Quarry to allow access to and interpretation of significant faces. This site has the potential to be designated an LNR.	**NCC**, AONB/EMS, NE	2010–2012
	5 Establish and deliver a Whin grasslands project which interprets and conserves the habitat and makes clear links to geodiversity.	**NWT**, AONB/EMS, NE, NT	2010–2012
	6 Ensure the preservation of selected sites and features associated with industrial use of geodiversity, such as Beadnell and Seahouses lime kilns and the Whinstone chippings silo base at Craster Harbour.	**NCC**, EH, AONB/EMS	2009–2014
	7 Consolidate Cocklawburn Limekilns (a fine example of cliff-top kilns and a striking landscape feature but now in disrepair). This could be achieved as part of a conservation and interpretation programme for this part of the coast.	**NCC**, EH, AONB/EMS, NE	2011

Interpreting our geodiversity

Objective	Action	Partners	Timescale
5 To increase awareness of the geological heritage of the coast as a whole.	1 Revise and reprint the Northumberland Coast Geology Booklet.	**AONB/EMS**, BGS	2010
	2 Include a geological element in talks and presentations about the coast's natural heritage.	**AONB/EMS**, NWT, NT	2009–2014
	3 Include geologically themed events and activities in the annual programmes of partners.	**AONB/EMS**, NWT, NT	2009–2014
	4 Maintain a photographic record of sites/features of Earth science importance.	AONB/EMS	2009–2014
	5 Establish an oral history project with former workers in the quarry industry of the coast.	AONB/EMS	2011
	6 Produce a leaflet on the pebbles of the Northumberland Coast.	AONB/EMS	2011
6 To interpret a series of priority sites and features of geological interest, integrated with interpretation of other aspects of the area's heritage.	**AMBLE TO EMBLETON**		
	1 Provide a geological element to guided boat trips to Coquet Island.	**AONB/EMS**, operators	2010–2014
	2 Interpret raised beaches at Alnmouth and Birling Carrs with discreetly sited static interpretation.	AONB/EMS	2010–2011
	3 Use Longhoughton Steel as a location for short guided walks, interpreting Whin Sill formation, boulder clay cliffs, dewatering features in sandstones, cheviot lavas and limestones (including the environments in which they were formed).	AONB/EMS	2010–2014
	4 Interpret brachiopods, trace fossils and crinoids at Sugar Sands Bay in any guided walks in the area.	AONB/EMS	2009–2014
	5 Improve parking area at Rumbling Kern / south of Howick by public footpath to bay.	AONB/EMS, NE	2010–2011
	6 Improve access to Howick Bay in the area around the fault, near to the site current lifebuoy.	NE, landowner	2010–2011
	7 As part of a leaflet on Howick Bay, interpret: Yoredale cycles, cross bedding in sandstone, building stone in the Bathing House and nearby quarrying, siderite nodules, fossil amphibian footprints at southeast end of bay (including a representation of the creature in its environment), the Howick Fault, highly altered xenoliths of Carboniferous rocks engulfed within the Whin Sill and the presence of amygdales (large quartz and calcite-filled gas cavities within the dolerite), the Cullernose Dyke and the Whin Sill columns at Cullernose Point.	AONB/EMS, NE	2012

Interpreting our geodiversity

Objective	Action	Partners	Timescale
6 To interpret a series of priority sites and features of geological interest, integrated with interpretation of other aspects of the area's heritage.	8 Seek controlled access to Howick Quarry to interpret geological features including the Whin Sill.	**AONB/EMS**, quarry operator	2010–2014
	9 Provide interpretation of Craster's Whinstone quarrying heritage in the Craster Car Park, itself a former Whinstone quarry.	AONB/EMS, NWT	2010–2011
	10 Provide interpretation of Craster's Whinstone quarrying heritage at Craster Information Centre. This might take the form of an audio trail with GPS.	AONB/EMS	2010–2011
	11 Produce a linear geology trail from Craster Information Centre to Dunstanburgh Castle / Castle Point, interpreting quarry heritage, the harbour's Whinstone transportation past, Whinstone buildings in the village, the Whin Sill as the foundation for Dunstanburgh Castle, the intrusion of the Whin and the columnar jointing formed on cooling, and the lower contact rocks exposed at Castle Point.	AONB/EMS	2010–2011
	12 Include geodiversity interpretation, notably the Whin Sill and its intrusion, in guided boat trips to the Farne Islands.	**AONB/EMS**, NWT, operators	2009–2014
	13 Interpret the Whin Sill intrusion and whinstone quarrying at Embleton Quarry.	AONB/EMS, NWT	2012
	NEWTON POINT TO HARKESS ROCKS		
	14 In any interpretation at Beadnell, incorporate the Beadnell Lime Kilns and the coastal lime trade, Beadnell Dyke and the Carboniferous sedimentary section at the junction of the road to Swinhoe.	AONB/EMS	2009–2014
	15 Interpret the Whin Sill as the foundations of Bamburgh Castle in any interpretation of the Castle and its history.	AONB/EMS, NWT	2012
	16 Produce a short leaflet or unobtrusive panel for Harkess Rocks, interpreting Pahoehoe features in the Whin Sill, contact between the Whin Sill and altered limestones and the xenolith of baked shale in the Whin Sill.	AONB/EMS	2012
	BUDLE BAY TO THE SCOTTISH BORDER		
	17 Interpret sand dune development at Cheswick and Goswick Sands through guided events.	AONB/EMS	Ongoing
	18 At Saltpan Rocks, interpretation panels could replace those from 80s and 90s interpreting spectacular folds in the Eelwell Limestone.	AONB/EMS	2011

Interpreting our geodiversity

Objective	Action	Partners	Timescale
6 To interpret a series of priority sites and features of geological interest, integrated with interpretation of other aspects of the area's heritage.	19 A trail booklet / leaflet for the Saltpan Rocks / Cocklawburn area would allow deeper exploration of this fine area for discovering coastal geology and the social history of salt production linked to coal deposits (interpretation should refer to former salt production by evaporation of seawater fuelled by local coal).	AONB/EMS	2011
	20 Employ carefully sited fixed interpretation of Cocklawburn limestone quarries (including kilns and the flora on the lime-rich quarry spoil). These features would also feature in a booklet / leaflet on this stretch of coast (see action 7.18).	AONB/EMS	2011
	21 Interpret past coal mining at Scremerston as part of any guided events or trail publications for this area.	AONB/EMS	2009–2014
	22 Interpret synclines, anticlines, faulting and limestone fossils (trace fossils, brachiopods, crinoids) at the Skerrs, perhaps through a short leaflet to the area.	AONB/EMS	2013
	23 In any guided events or printed interpretation of the Marshall Meadows Bay area, interpret carboniferous strata, links to biodiversity, and the erosive power of the sea.	AONB/EMS	2013
	HOLY ISLAND		
	24 As a high priority, produce a geological trail guide to Holy Island. This would include: building stone in the priory and other buildings, the Holy Island Dyke, the creation of the island through post-glacial activity, glacial deposits, Coves Haven bay in soft shales, Whin grasslands, shingle raised beach at Castle Point, dune formation, folds in the Eelwell limestone, lime kilns, amygdales (large quartz and calcite-filled gas cavities within the dolerite at Steel End) and links between biodiversity, cultural heritage and geodiversity.	NE, Holy Island Partnership	2010
	25 Produce a Holy Island Building Stones Trail leaflet.	NE, Holy Island Partnership	2010
	26 Several points on Holy Island are ideal for carefully sited static interpretation highlighting the Holy Island Dyke, dunes, former limestone quarrying, building stones in the Priory and mud/sand flats.	AONB/EMS	2010
	27 Produce a 'Holy Island Loan Box'. This would include resources for education about geodiversity alongside those for biodiversity and cultural heritage' (*see 'Education and Lifelong Learning*).	AONB/EMS	2010

Education and lifelong learning about our geodiversity

Objective	Action	Partners	Timescale
7 To increase opportunities for schools to increase their use of the coast for the study of Earth science.	1 Produce geologically themed education resource material in partnership with teachers, either as a standalone project or as part of other resources for the coast, and make it available on the 'our coast our sea' website www.ourcoastoursea.org.uk.	AONB/EMS, quarry operators	2010–2011
	2 Produce a set of 'Northumberland Coast Loan Boxes' as part of the education resources an as a stand alone product. The would include resources for education about geodiversity alongside those for biodiversity and cultural heritage'.	AONB/EMS	2010–2011
	3 Hold a twilight session for teachers to promote the resources produced through actions 8.1 and 8.2 and to showcase opportunities to deliver the curriculum which are provided by the coast's geodiversity.	AONB/EMS	2011–2012
	4 Support school travel grants for education visits to the coast. This is likely to be part of the wider work of the Coast teams.	AONB/EMS	2010
	5 Encourage the use of local buildings, structures, graveyards, etc. as local educational resources to introduce children to the varied range and uses of geological materials.	AONB/EMS	2009–2014
	6 Work with media artists and a local school to produce a short film about the geology and landscape of the coast.	AONB/EMS	2011
8 To support lifelong learning about the coast's Earth heritage.	1 Incorporate an Earth heritage aspect into lifelong learning activities focused on the coast's natural environment.	AONB/EMS, NWT, NT	Ongoing
	2 Run a series of evening classes on the Earth heritage of the coast.	AONB/EMS. UNI, WEA	2010, 2012, 2014
	3 Ensure the continuation of an Earth heritage aspect to the Coast and Country programme for tourism providers.	AONB/EMS	2010
	4 Establish a children's nature club on the coast and ensure a strong geological element to the activities.	AONB/EMS, NWT	2010
	5 Hold an annual geology and landscape painting weekend with an element of geological interpretation to help provoke the work of participants.	AONB/EMS	Annual
	6 Encourage the expansion of existing groups with an interest in geodiversity, or the formation of new ones.	AONB/EMS, RIGS, NWT, NNHS	

Selected References, Reading List and Maps

What follows is a brief summary of the main references which will provide more detail on the issues covered in this document. A full list is available from the AONB/EMS Partnerships.

Books and reports

As already noted, details of the AONB's geology are covered in an extensive technical literature. It is neither appropriate, nor possible, to attempt a comprehensive list of these publications. Instead, the following brief list includes the most important summaries and regional syntheses of information relevant to the understanding and application of the geodiversity of the AONB. The publications listed below should be regarded as essential works of reference for this purpose. All include substantial lists of the most important detailed papers and reports in the scientific press that relate to key aspects of the district's geodiversity.

BRIDGELAND, D.R., HORTON, B.P. and INNES, J.B. (editors). 1999. The Quaternary of North-east England. Field Guide. Quaternary Research Association, London.

A detailed introduction to the Quaternary geology of the region, including much of importance in the AONB. Includes several field guides to parts of the AONB and adjoining areas.

BROWN, A.E., CAMPBELL, W.A., ROBSON, D.A. and THOMAS, E.R. 1961. Musical sand; the singing sands of the seashore. Part 1. *Proceedings of the University of Durham Philosophical Society*. Series A, Vol.13, No.21, pp217–230.

CARRUTHERS, R.G., BURNETT, G.A. and ANDERSON, W. 1930. The geology of the Alnwick District. Memoir of the Geological Survey of Great Britain. HMSO, London.

A detailed technical description of the geology of the area covered by BGS 1:50 000 Sheet 6. An essential reference for geological features within this area.

CARRUTHERS, R.G., DINHAM, C.H., BURNETT, G.A. and MADEN, J. 1927. The geology of Belford, Holy Island, and the Farne Islands. Memoir of the Geological Survey of Great Britain. HMSO, London.

A detailed technical description of the geology of the area covered by BGS 1:50 000 Sheet 4. An essential reference for geological features within this area.

CHADWICK, R.A., HOLLIDAY, D.W., HOLLOWAY, S. and HULBERT, A.G. 1995. The structure and evolution of the Northumberland-Solway basin and adjacent areas. Subsurface memoir of the British Geological Survey. HMSO, London.

A very detailed technical exploration of the deep structure of Northumberland and its geological evolution over time. An essential reference for geological features within this area.

CROSSLEY, C. and YOUNG, B. 2005. Explore the geology and landscape of the Northumberland Coast Area of Outstanding Natural Beauty. Northumberland County Council, Morpeth.

An introduction, for readers with little or no previous knowledge of geology, to the geology and landscape, with more detailed descriptions of the geological features of interest visible on key sections of the coast

FOWLER, A. 1926. The geology of Berwick-upon-Tweed, Norham and Scremerston. Memoir of the Geological Survey of Great Britain. HMSO, London.

A detailed technical description of the geology of the area covered by BGS 1:50 000 Sheets 1 & 2. An essential reference for geological features within this area.

FOWLER, A. 1936. The geology of the country around Rothbury, Amble and Ashington. Memoir of the Geological Survey of Great Britain. HMSO, London.

A detailed technical description of the geology of the area covered by BGS 1:50 000 Sheet 9. An essential reference for geological features within this area.

JOHNSON, G.A.L. (editor). 1995 (2nd edition). Robson's Geology of North East England. Transactions of the Natural History Society of Northumbria, Vol.56, Part 5.

A detailed review of the geology of the whole of north-east England.

LAWRENCE, D.J.D., ARKLEY, S.L.B., EVEREST, J.D., CLAKE, S.M., MILLWARD, D., HYSLOP, E.K., THOMPSON, G.L. and YOUNG, B. 2007. Northumberland National Park. Geodiversity Audit and Action Plan. British Geological Survey Commissioned Report, CR/07/037N.

The first work of its type to consider geodiversity in Northumberland. An important companion volume to this document, it reviews the geodiversity of the areas adjoining the Northumberland Coast AONB.

SCRUTTON, C.T. (editor). 2004 (2nd edition). Northumbria rocks and landscape. A field guide. Yorkshire Geological Society.

A series of self guided excursions to demonstrate key areas of north-east England geology. Includes a simplified and easily understood general introduction to the region's geological evolution.

STANLEY, M. 2001. 'Welcome to the 21st Century', *Geodiversity Update*, No.1, p1.

TAYLOR, B.J., BURGESS, I.C., LAND, D.H., MILLS, D.A.C., SMITH, D.B. and WARREN, P.T. 1971 (4th edition). British Regional Geology. Northern England. HMSO, London.

A general description of the geology of the whole of northern England from Teesside and Morecambe Bay northwards to the Scottish Border with much relevant to the AONB. Now out of print, a new edition is currently in press. An essential reference for geological features within this area.

Geological Conservation Review Volumes

A systematic review, to identify and help conserve, British geological sites of national and international importance, was begun by the Nature Conservancy Council in 1977. This process, known as the Geological Conservation Review (GCR), was completed in 1990 under the auspices of the Joint Nature Conservancy Committee (JNCC). The results of the review, including detailed descriptions of the sites identified, are being published in a series of volumes written for a specialised scientific readership. Those volumes which include descriptions of sites within the AONB are listed below, together with the introductory volume for the GCR series.

ELLIS, N.V. (editor), BOWEN, D.Q., CAMPBELL, S., KNILL, J.L., McKIRDY, A.P., PROSSRR, C.D., VINCENT, M.A. and WILSON, R.C.L. 1996. *An introduction to the Geological Conservation Review*. GCR Series No. 1, Joint Nature Conservation Committee, Peterborough.

CLEAL, C.J. and THOMAS, B.A.. 1996. *British Upper Carboniferous Stratigraphy*. GCR Series, Joint Nature Conservation Committee, Peterborough and Chapman & Hall, London.

COSSEY, P.J., ADAMS, A.E., PURNELL, M.A., WHITELEY, M.J., WHYTE, M.A. and WRIGHT, V.P. 2004. *British Lower Carboniferous Stratigraphy*. GCR Series, Joint Nature Conservation Committee, Peterborough.

HUDDART, D. and GLASSER, N.F. 2002. *Quaternary of Northern England*. GCR Series, Joint Nature Conservation Committee, Peterborough.

MAY, V.J. and HANSOM, J.D. 2003. *Coastal geomorphology of Great Britain*. GCR Series, Joint Nature Conservation Committee, Peterborough.

STEPHENSON, D., LOUGHLIN, S.C., MILLWARD, D., WATERS, C.N. and WILLIAMSON, I.T. 2003. *Carboniferous and Permian Igneous Rocks of Great Britain North of the Variscan Front*. GCR Series, Joint Nature Conservation Committee, Peterborough and British Geological Survey, Keyworth, Nottingham.

Maps

Onshore geological maps

1:50 000 or 1:63 360 scale

The most widely available geological maps in Great Britain are published at these scales. These maps give an excellent picture of the local geology and are suitable for a wide range of uses. However, for more detailed, or site-specific information, mapping at the 1:10 000 or 1:10 560 scale is required (see below).

It is normal in Great Britain for geological maps at these scales to be available in two editions:

- The 'solid', or 'bedrock', edition depicts the distribution and configuration of bedrock geology as if all superficial deposits of Quaternary age were removed; and
- The 'drift', or 'superficial', edition depicts the Quaternary geology, usually unconsolidated deposits that include those of glacial and post-glacial origin. Made ground, worked ground and landscaped ground may also be shown.

The Northumberland Coast AONB, and its immediately adjoining areas, is covered by the following British Geological Survey 1:50 000 and 1:63 360 scale sheets:

Sheet 1 & 2 Berwick-upon-Tweed and Norham

Published at the 1:63 360 scale as separate 'solid' and 'drift' editions of Sheets 1 and 2 in 1926. Reissued as one sheet at the 1:50 000 scale with separate 'solid' and 'drift' editions printed on the same map and incorporating marginal additions and amendments in 1977.

Sheet 4 Holy Island

Published at the 1:63 360 scale as separate 'solid' and 'drift' editions in 1925. 'Solid' edition reissued at the 1:50 000 scale without amendment in 1974. 'Drift' edition still available only at 1:63 360 scale.

Sheet 6 Alnwick

Published at the 1:63 360 scale as separate 'solid' and 'drift' editions in 1930. Reissued at the 1:50 000 scale in separate 'solid' and 'drift' editions without amendment in 1972.

Sheet 9 Rothbury

Published at the 1:63 360 scale in 1934. 'Drift' edition reissued at the 1:50 000 scale without amendment in 1977. New editions, of both 'solid' and 'drift' geology, based on a recent revision survey, are in press.

1:10 000 or 1:10 560 scale

Geological field mapping in Great Britain is today normally carried out at 1:10 000 scale (1:10 560 scale prior to the advent of metric scale maps). The results of these surveys are published as maps at these scales. For many areas these published maps are available only as copies of hand coloured manuscript versions of the sheet. These maps are used to compile maps at 1:50 000, or smaller, scale, though considerable editing and generalisation of geological detail is usually necessary, especially in areas of geological complexity.

Geological maps at 1:10 000 or 1:10 560 scale are published in only one edition, in which both bedrock ('solid') and superficial ('drift') geology are depicted on the same sheet.

Geological maps at 1:10 000 or 1:10 560 scale are necessary where detailed site-specific information is required, for example for most site investigation, building or detailed planning purposes.

The incidence of 1: 10 000 or 1:10 560 or scale map sheets is shown on the marginal information of 1:63 360 or 1:50 000 scale geological maps. More detail on coverage, date of survey, style, availability etc. of these large scale maps may be obtained from offices of the British Geological Survey.

For the Northumberland Coast AONB large scale geological mapping is available solely at the 1:10 560 scale, except for the area covered by 1:50 Sheet 9 (Rothbury). For this area, 1:10 000 scale maps resulting from the most recent field survey, are available.

Geological and related maps at other scales

The geology of the AONB is also depicted on geological maps at1:2 500 000, 1:1 000 000, 1:625 000, 1:584 000, 1:500 000, and 1:250 000 scales. At these scales the level of detail is small, but the maps are useful in placing the district in its wider national context. Included in these smaller scale maps are maps that depict aspects of geophysics, mineral resources and geochemistry.

Offshore geological maps

Until very recently, British Geological Survey 1:50 000 and 1:63 360 scale geological maps depicted onshore geology only. In recent years, where possible, new editions of maps at the 1:50 000 scale incorporate information on offshore geology. Ideally as a continuation of onshore mapping at 1:50 000 scale.

For Northumberland, the only 1:50 000 sheet on which offshore geology is depicted is Sheet 10 (Newbiggin), published in 1997, which covers the area immediately south of the AONB. The offshore geology is depicted in a much generalised form than for onshore areas.

The following British Geological Survey maps depict the offshore geology of the coast adjacent to the AONB.

At the 1:250 000 scale:

Sheet 55N 02W Farne. Solid edition

Depicts 'solid' geology both onshore and offshore. The geology of offshore areas is much more generalised than for onshore areas. Published 1988.

Sheet 55N 02W Farne. Quaternary edition.

Depicts Quaternary geology in offshore areas only. Published 1988.

Sheet 55N 02W Farne. Seabed sediments edition.

Published 1989.

At the 1:1 000 000 scale:

Geology of the United Kingdom, Ireland and continental shelf: North sheet (Solid).

Depicts the solid geology both onshore and offshore. Published 1991.

Quaternary Geology around the UK: North sheet.

Depicts the Quaternary geology ('drift' deposits) of the offshore area only. Published 1994.

Historical geological maps

Of historical interest as important early contributions to understanding of the geology of the Northumberland coast are two maps by William Smith, the so-called 'Father of English geology', published in 1815 The first of these, which covers England, Wales and the southern part of Scotland, was originally published as a series of 15 parts at a scale of five miles to the inch. The complete map has been digitally scanned and published at half scale (ten miles to the inch) by the British Geological Survey. The seconds is Smith's slightly later (1820) geological map of England and Wales, with important emphasis on coal and other mineral resources. Reproductions of both of these maps are available from the British Geological Survey.

Glossary

Some descriptions have already appeared in the run of the text and are not repeated here.

Amygdale	A gas cavity in an igneous rock that has been filled with later minerals
Anticline	A convex upwards, or arch-like, fold in rocks, with the oldest rocks in the centre
Bedding	The layering in sedimentary rocks parallel to the original surface of deposition
Bivalve	A class of molluscs with paired shell valves
Brachiopod	A phylum of solitary marine invertebrates with shells made of two unequal valves
Calcareous	Containing calcium carbonate
Cementstone	A limestone with a significant clay content that may be suitable for making cement. Also used in Northumberland as a formal, though now obsolete, name for a succession of Lower Carboniferous rocks in which cementstones are common
Chronostratigraphy	The standard hierarchical classification of geological time units
Conglomerate	A coarse-grained sedimentary rock composed of more or less rounded fragments at least 2 mm in diameter in a matrix of sand, silt or clay
Crinoid	Marine animals, often known as 'sea lillies', composed of calcareous plates, belonging to the phylum Echinodermata
Cross-bedding	Internally inclined layers in a rock related to the original direction of current flow
Dolerite	A medium-grained igneous rock composed of the minerals pyroxene, plagioclase feldspar and iron and titanium oxides.
Dolomite	A mineral composed of calcium magnesium carbonate ($CaMg(CO_3)_2$)
Dyke	Discordant, sheet-like bodies of intrusive igneous rock in a vertical, or near-vertical, orientation
Esker	A long, narrow, sinuous or straight ridge composed of glacial meltwater deposits, usually including large amounts of sand and gravel
Fault	A fracture in rocks along which some displacement has taken place
Feldspar	A group of rock-forming minerals consisting of silicates of aluminium, sodium, potassium, calcium and, more rarely, barium
Fesite	A general term used to denote a light-coloured fine-grained igneous rock composed of quartz and feldspar
Hornfels	A fine-grained rock adjacent to an igneous intrusion, that has been partly or wholly recrystallised by heat from the intrusion
Igneous rock	A rock that has formed from the cooling and crystallisation of molten rock, or magma
Limestone	A sedimentary rock composed mostly of calcium carbonate
Magma	Molten rock
Marble	A fine to coarse-grained metamorphic rock composed of crystalline calcite (calcium carbonate) and formed by the alteration of limestone
Metamorphic rock	A rock that has been formed by the alteration (metamorphism), usually by heat and/or pressure, from a pre-existing rock
Mudstone	A fine-grained sedimentary rock composed of mud sized particles
Orogeny	An episode in earth history that produced folding and dislocation of rocks that resulted in regional uplift and mountain building
Pahoehoe	The 'ropy', undulating ridge-like surfaces found on the surfaces, or inside gas cavities, of some igneous rocks, resulting from flow during cooling. The term originated in Hawaii, where such features are common in some lava flows
Ripple marks	Small-scale ridges and troughs formed by the flow of water or wind over unconsolidated sand or silt. Ripple marks in sandstones are the fossilised equivalent of the ripples found today on river or beach sands
Seatearth	The fossil soil underlying a coal seam. Seatearths may be sandstones, siltstones of mudstones

Sedimentary rock	A rock formed by the accumulation of fragments produced by the wasting of pre-existing rocks or organic materials, deposited as layers of sediment
Sill	A tabular igneous intrusion with more or less concordant contacts with the surrounding wall rocks
Stratigraphy	The definition and description of the stratified rocks of the Earth's crust
Syncline	A concave-downwards, or trough-like, fold in rocks, with the youngest rocks in the centre
Throw	The amount of vertical displacement on a fault

Notes

Notes

Northumberland Coast AONB Partnership
c/o County Hall
Morpeth,
Northumberland
NE61 2EF

This Geodiversity Audit and Action Plan was produced by Brian Young with Chris Woodley-Stewart on behalf of the Northumberland Coast AONB and European Marine Site Partnerships. Original illustrations are by Elizabeth Pickett. Photography by Brian Young unless otherwise credited in the text. Front cover (repeated page 15) and back cover photographs © Northumberland Coast AONB/Gavin Duthie.

Produced on behalf of the Northumberland Coast AONB Partnership and Berwickshire & North Northumberland European Marine Site Partnership

NORTHUMBERLAND COAST

Supported by:

Northumberland

Northumberland County Council

NATURAL ENGLAND