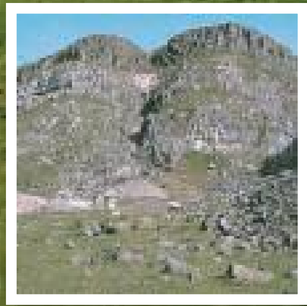
North Pennines

Area of Outstanding Natural Beauty and European Geopark

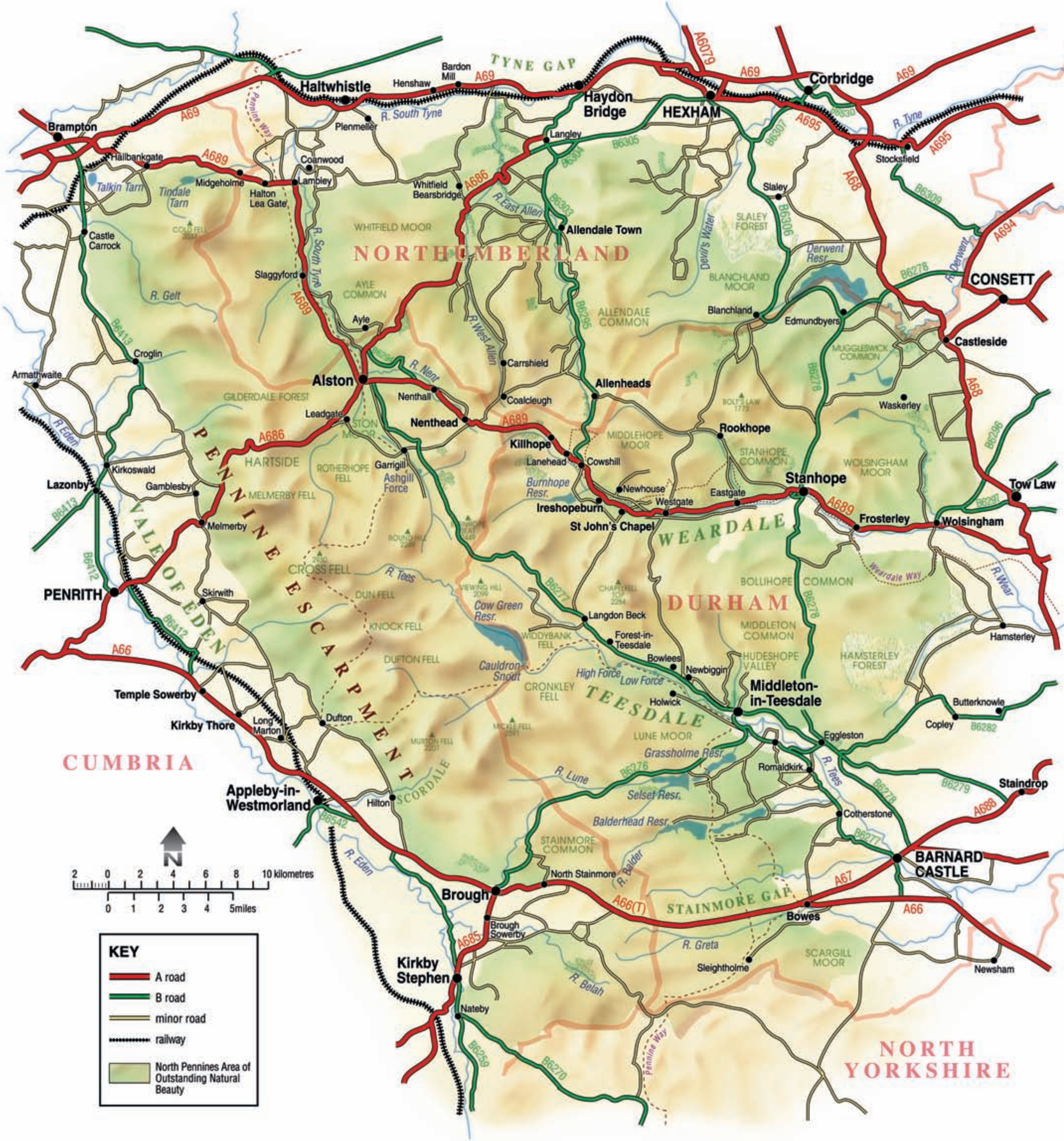
A Geodiversity Audit

Revised March 2010


NORTH PENNINES
Area of Outstanding Natural Beauty

Geoparks


NORTHUMBERLAND
DURHAM
CUMBRIA
NORTH YORKSHIRE
TYNE GAP
PENNINE ESCARPMENT
VALE OF EDEN
WEARDALE
TEESDALE
STAINMORE GAP
Haltwhistle
Brampton
Haydon Bridge
HEXHAM
Corbridge
Stocksfield
Bardon Mill
Henshaw
Plenmeller
Langley
Hallbankgate
Coanwood
Lambley
Midgeholme
Halton Lea Gate
Talkin Tarn
Tindale Tarn
Whitfield Bearsbridge
Allendale Town
Slaley
SLALEY FOREST
Derwent Resr.
CONSETT
Castle Carrock
Slaggyford
WHITFIELD MOOR
AYLE COMMON
ALLENDALE COMMON
BLANCHLAND MOOR
Blanchland
Edmundbyers
Castleside
MUGGLESWICK COMMON
Ayle
Croglin
Armathwaite
Alston
Carrshield
Allenheads
Coalcleugh
Nenthall
Nenthead
Leadgate
GILDERDALE FOREST
Waskerley
Rookhope
Killhope
Lanehead
Cowshill
MIDDLEHOPE MOOR
STANHOPE COMMON
WOLSINGHAM MOOR
Stanhope
Eastgate
Westgate
Newhouse
Ireshopeburn
St John's Chapel
Frosterley
Wolsingham
Tow Law
Burnhope Resr.
Kirkoswald
Lazonby
Gamblesby
HARTSIDE
ROTHERHOPE FELL
Garrigill
Ashgill Force
MELMERBY FELL
Melmerby
CROSS FELL
DUN FELL
KNOCK FELL
DUFTON FELL
PENRITH
Skirwith
Cow Green Resr.
WIDDYBANK FELL
Cauldron Snout
Langdon Beck
Forest-in-Teesdale
BOLLIHOPE COMMON
MIDDLETON COMMON
HUDESHOPE VALLEY
HAMSTERLEY FOREST
Hamsterley
Bowlees
Newbiggin
High Force
Low Force
CRONKLEY FELL
Holwick
Middleton-in-Teesdale
Butterknowle
Copley
Temple Sowerby
Kirkby Thore
Long Marton
Dufton
LUNE MOOR
Grassholme Resr.
Eggleston
Romaldkirk
Staindrop
Appleby-in-Westmorland
Hilton
SCORDALE
R. Lune
Selset Resr.
Balderhead Resr.
Cotherstone
STAINMORE COMMON
BARNARD CASTLE
North Stainmore
Brough
Brough Sowerby
Bowes
Kirkby Stephen
Sleightholme
SCARGILL MOOR
Newsham
Nateby
R. Greta
R. Belah
R. Eden
R. Tees
R. Wear
R. Tyne
R. South Tyne
R. Nent
R. West Allen
R. East Allen
R. Gelt
R. Derwent
Devil's Water
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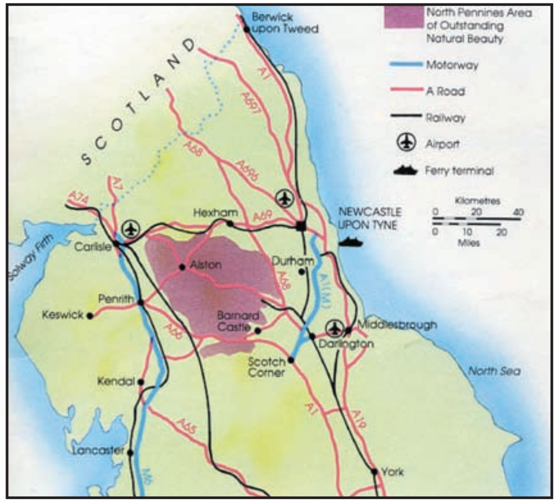
North Pennines Area of Outstanding Natural Beauty


North Pennines Area of Outstanding Natural Beauty
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A Road
Railway
Airport
Ferry terminal
Kilometres
0 20 40
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Miles
SCOTLAND
Berwick upon Tweed
Hexham
NEWCASTLE UPON TYNE
Carlisle
Alston
Durham
Penrith
Keswick
Barnard Castle
Middlesbrough
Darlington
Scotch Corner
Kendal
Lancaster
York
North Sea
Solway Firth
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A68
A696
A69
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A66
A65
A19
A1(M)
M6

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Introduction

Partly in recognition of the area's special geological significance, though also in recognition of local efforts to conserve and interpret Earth science, the North Pennines AONB was the first area in Britain to be awarded the UNESCO-endorsed status of 'European Geopark' in June 2003.

Following that designation, and in order to establish a sound framework and knowledge-base for ongoing programmes of geologically related interpretation, conservation and other activities, in 2003 the AONB Partnership commissioned the British Geological Survey (BGS) to prepare a comprehensive Geodiversity Audit of those geological features present within the AONB. Based upon this audit, and in close collaboration with staff of BGS, the North Pennines AONB Staff Unit prepared a detailed Local Geodiversity Action Plan (LGAP) to guide their work in furthering the interests of geodiversity within the AONB. The Audit and Action Plan were published as a joint document in 2004 (AONB, 2004), the first document of its kind for a protected landscape in Great Britain.

With many of the objectives and action points identified in this original Action Plan successfully completed, a new Action Plan is required for the next five years.

Fundamental to, and underpinning, the framing of any such action plan is an authoritative and comprehensive modern audit of all of those features which comprise the geodiversity resources of the area being considered. Here in the North Pennines, the AONB Partnership believes that the original Audit, published with the LGAP in 2004, provided just such a foundation. Indeed, as was intended at the time of its compilation, the Audit was designed to stand as a reliable reference source for many years beyond the scope of the first Action Plan. With the launch of the new Action Plan, the opportunity has been taken to prepare this revision of the original Audit to incorporate major new work on the area's geology published since 2004, to take into account developments undertaken in response to the original Action Plan, and to reflect such changes as the pattern of mineral working. The Audit is here presented as a separate document intended to inform not only the new Action Plan, but to serve as an authoritative reference source to all who need access to expert information on the wide range of geological features, materials and processes which have shaped and continue to shape, the geodiversity of the AONB.

Revision of the Audit has been undertaken by Brian Young, retired BGS District Geologist for Northern England, in collaboration with Chris Woodley-Stewart and Elizabeth Pickett of the North Pennines AONB Partnership.

Jeffrey's chimney above Ramshaw © Elizabeth Pickett/NPAP

"North of Nenthead" – Charlie Hedley © Countryside Agency.

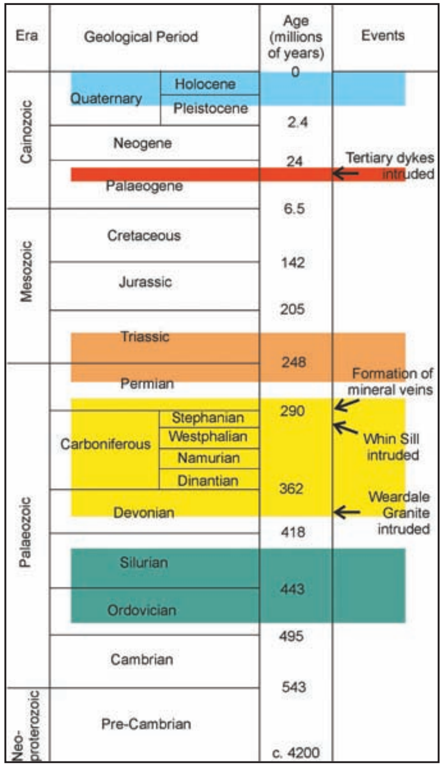
"Dufton Pike (left), Knock Pike (right) and Dufton Fell" – Charlie Hedley © Countryside Agency.

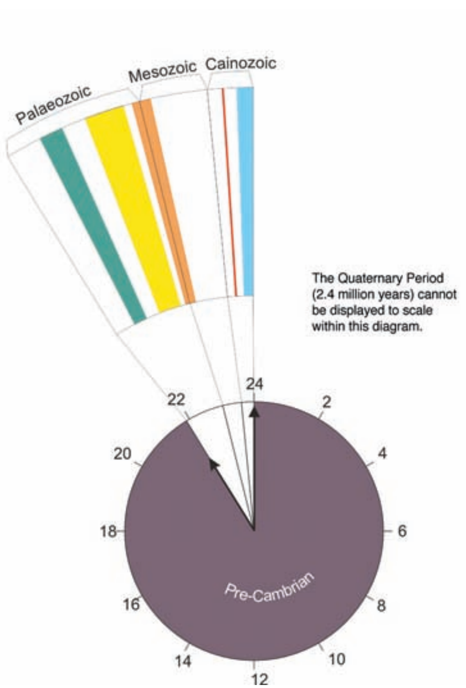
A Geodiversity Audit

Geological Time

The rocks of the North Pennines are 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 almost half a billion 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. Because such an immense span of time is almost impossible to conceive, it is helpful to represent the whole of Earth history by a single day. On this basis, the oldest rocks present within the AONB, which date back to about 495 million years ago, were formed at around 10.00 in pm; the limestones and sandstones that make up much of the fells date from between 10.30 and 11.00 pm; 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 Era and Periods, as shown in the diagram. Those geological periods, or parts of periods, represented by rocks within the AONB are highlighted. Significant events in the geological history of the AONB are indicated alongside the column.

The Geological Evolution of the North Pennines AONB

Before examining in detail the varied rocks and geological features that together comprise the AONB's geodiversity, and in order to help view these in their true context, it is worth considering briefly the main processes and events which, over geological time, have shaped the area we today know as the North Pennines. Of necessity, this is a very brief summary; more detailed accounts can be found in the literature references cited in the bibliography.

The diversity of North Pennines rocks, their composition, structure, the fossils and minerals they contain, enable geologists to decipher the history and evolution of the area. It is a story which can be traced back over almost 500 million years. However, the record, as contained in the rocks, is incomplete. The diagram opposite illustrates the main periods of geological time and indicates those periods for which there is clear evidence preserved in the rocks of the AONB. For much longer periods of time, the area contains no rocks and thus no direct evidence of events or conditions. For any interpretation of these periods we must rely upon information gathered from the rocks formed elsewhere at these times.

The oldest rocks known in the AONB date from the Ordovician and Silurian periods of Earth history, between 495 and 418 million years ago. The configuration of landmasses across the earth was then very different from today. At this time the area which was to become the North Pennines lay south of the equator, where it formed part of a deep ocean, known to geologists as the Iapetus Ocean, on the northern edge of a continental plate, known as Eastern Avalonia. Mud and sand, which accumulated in this ocean, are preserved today as the mudstones and sandstones of the Skiddaw Group. Eastern Avalonia was then moving gradually northwards towards another huge continent, known as Laurentia, which included what would eventually become Scotland and much of North America. Huge stresses in the earth's crust, caused by the movement of these continents, resulted in the enormous volcanic eruptions which created an enormous thickness of volcanic rocks, known as the Borrowdale Volcanic Group. Further accumulation of muds and sands formed the vast thickness of rocks known today as the Windermere Supergroup. As these continents finally collided, the Iapetus Ocean was destroyed and crumpling of the rocks brought into being a new mountain chain across what is now northern England.

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

The Ordovician and Silurian rocks, which are known to underlie the whole of Northern England, are best seen at the surface today in the Lake District, but are also exposed along the foot of the

North Pennine escarpment and in a small part of Upper Teesdale, where they emerge from beneath their cover of Carboniferous and younger rocks. They have also been proved in a handful of deep boreholes in the North Pennines and adjoining areas.

There are few rocks in northern England which can be reliably dated to the period of earth history known as the Devonian period, between about 400 and 360 million years ago. However, conglomerates exposed locally on the Pennine escarpment may represent accumulations of boulders and gravels deposited amongst the eroding mountains.

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

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

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

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

Major earth movements towards the end of Carboniferous times once more created mountains across what became northern England. By about 280 million years ago, during the Permian Period, the area which was to become the North Pennines lay within tropical latitudes and became an arid desert. Rapid erosion by flash floods built up fans of debris at the foot of the mountains; shifting sand dunes developed on the flatter ground. We see these today as the Brockram and Penrith Sandstone respectively, in the Vale of Eden.

By the onset of Triassic times, about 245 million years ago, the area which is now Cumbria was a wide plain crossed by vast meandering rivers, building up the deposits we know today as the Eden Shales and the St Bees Sandstone.

From about 230 million years ago evidence for the area's geological evolution falls largely silent. We know that during the Palaeogene Period, about 65 million years ago, narrow dykes of basaltic rock were injected into fractures as distant manifestations of the vast volcanic activity associated with the opening of the Atlantic Ocean that was then shaping the Hebrides and Northern Ireland. Apart from this we have no tangible evidence of our area's geological history until the deposits left by ice sheets during the glacial period which began here about 2 million years ago. Much of the form of the present day landscape derives from the effects of this prolonged period of ice cover and its subsequent melting.

Centuries of human occupation and exploitation of the area's natural resources, have further modified the landscape into that which we see today. This landscape is still evolving through continuing human influence. The challenge for the conservation of the area is to encourage beneficial change without detracting from its overall character.

Selected references

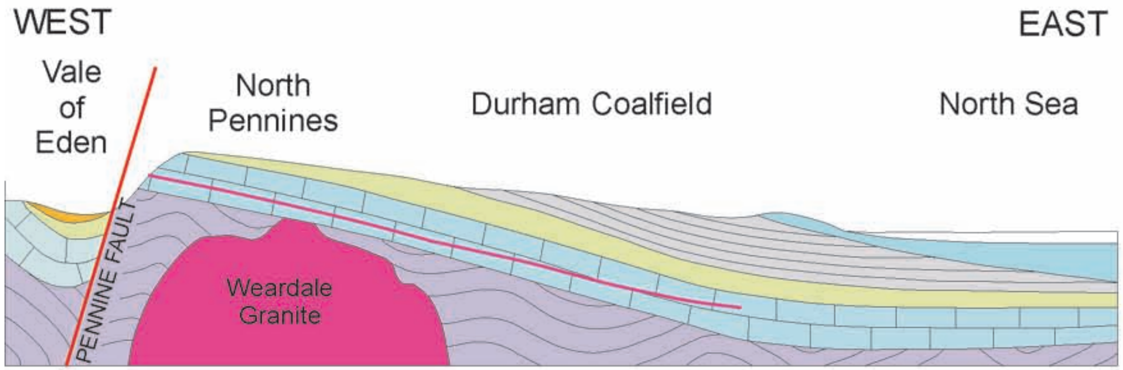
Dunham, 1990; Johnson, 1970, 1995; Stone et al, 2010.

A SIMPLIFIED GEOLOGICAL MAP OF THE NORTH PENNINES AONB

KEY

- **Permian** – mainly limestones and dolomites with sands at the base (illustrated in cross section only)
- **Permo-Triassic** – mainly red sandstones, mudstones and some breccias
- **Westphalian - *the Coal Measures*** – shales, siltstones, sandstones and coal seams
- **Namurian** – alternations of thin limestones, shales and thick sandstones with thin coal seams, includes the Great Limestone
- **Dinantian** – alternations of limestone, shale, sandstone and coal with conglomerates, shales and sandstones at the base
- **Devonian** – mainly conglomerates
- **Ordovician and Silurian** – mainly slates, impure sandstones and volcanic rocks
- **Igneous intrusions** – Dolerite, part of the *Whin Sill* suite of intrusions and the *Cleveland-Armthwaite Dyke,* and the Weardale Granite

N.B. For clarity, faults and minerals veins are omitted from this map.



Diagrammatic Cross-section. Vertical scale greatly exaggerated

The North Pennines' Place in the Development of Geological Science

Geological science developed in large part from the observations and deductions made by practical miners and civil engineers. Their observations and deductions relate to geological sites and features which may still be visible today.

As one of the earliest worked, and economically most important, of Britain's metalliferous orefields, the North Pennines was an important centre for the application of geological principles long before geological science, as we recognise it today, emerged.

There can be little doubt that much successful mineral exploration and working in early centuries was made possible only by the skilful application of hypotheses developed through systematic observation by countless unknown and forgotten miners. By the early 19th Century, several local figures emerge in the contemporary scientific literature as significant leaders in what was eventually to be seen as geological science. Notable figures include Westgarth Forster, William Wallace and Thomas Sopwith. Although many of their ideas are now outdated, and in some instances discredited, their contributions to the development of understanding of North Pennine geology are undeniable, and stand as important milestones in the wider development of geological science.

Throughout subsequent years the area has been a fertile source of inspiration for research. Particularly notable is the seminal work of Sir Kingsley Dunham, who together with research colleagues such as Professor Martin Bott, developed the hypothesis of a buried granite beneath the North Pennines to explain the origins and nature of the area's mineral veins. The proving of this granite in the Rookhope Borehole was to prove a major milestone in the evolution of thinking on ore-forming processes worldwide.

The north of England has given geological science one of its most familiar terms. To the North Pennine miner a 'sill' was any more or less horizontal body of rock. The name 'whin', meaning hard, black and intractable, was applied to one particular unit. When, in the 19th Century, the intrusive igneous nature of the Whin Sill was recognised, the term sill was soon adopted worldwide for intrusive bodies of this sort. It is not known exactly where in northern England the term Whin Sill was first used by miners and quarrymen, though the North Pennines seems highly probable.

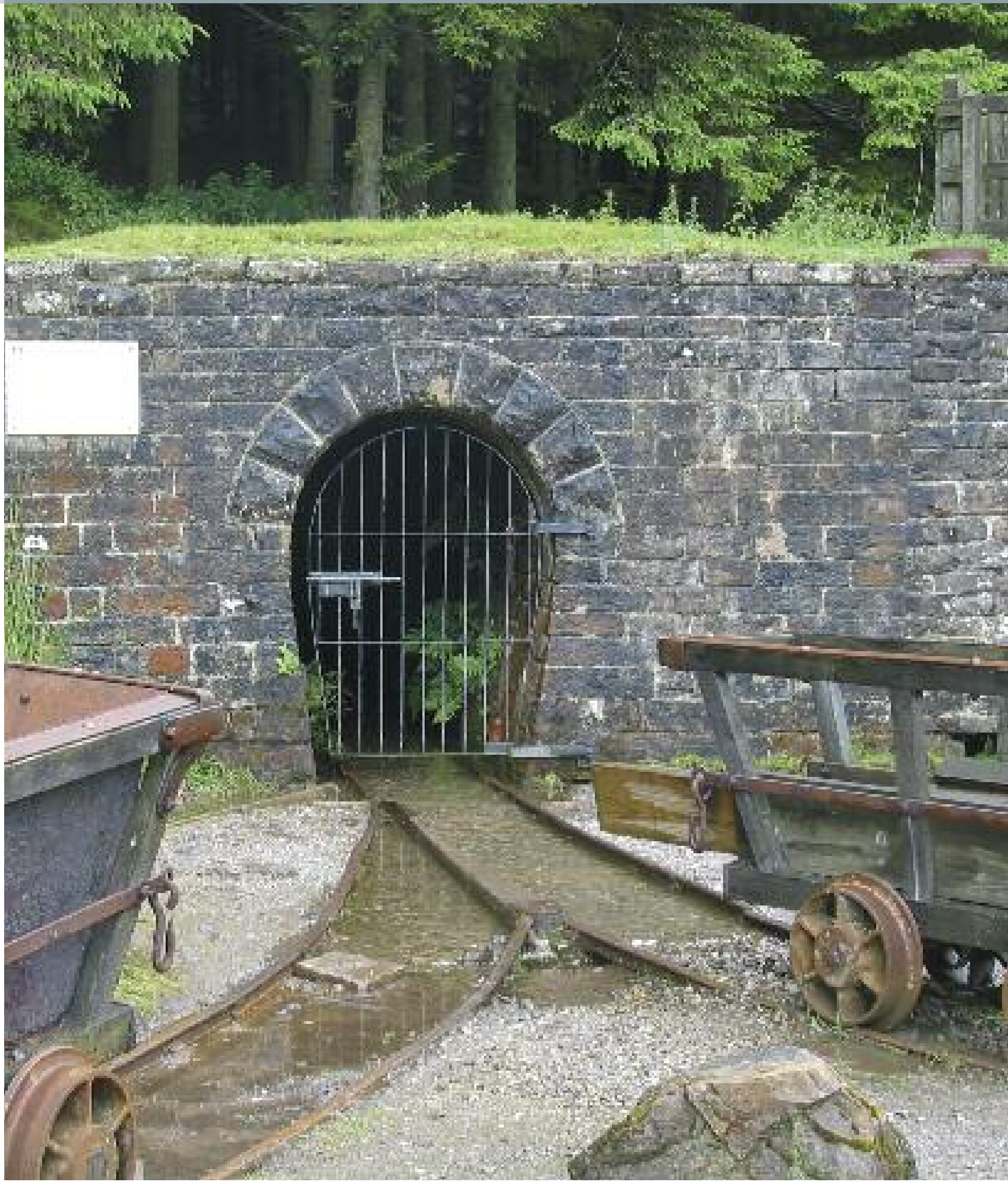
The AONB also includes the type locations for four mineral, and several fossil, species, first discovered here.

The area is still, and is likely to remain, a focus for much significant geological research both in its own right and as a component part of the geology of Great Britain and Europe.

This Geodiversity Audit and its first accompanying Action Plan was the first such document published for any protected landscape in Great Britain.

Selected references

Dunham, 1990; Forbes et al, 2003; Forster, 1809; Johnson, 1970, 1995; Sopwith, 1833; Stone et al, 2010; Wallace, 1861.



Park Level, Killhope © Elizabeth Pickett/NPAP

The Geological Framework

At the heart of the area's geodiversity is the succession of rocks, which together comprise and characterise the North Pennines. In the following pages, deposits of particular geological ages, together with intrusive igneous rocks, metamorphic rocks, mineral veins, geological structures, minerals and fossils are reviewed separately. In addition, topics such as Frosterley Marble, geological models and spar boxes, many of which are of particular local importance, or in some instances unique, to the AONB are also given separate consideration.

For each of these topics, essential details of their defining characteristics are outlined, together with comments on their place within the wider context of the geology of Great Britain. The impact of these geological features or materials on landscape and biodiversity, as well as any economic uses, are also considered. Sites currently afforded any form of protection are listed and some of the most significant literature sources also referenced.

Ordovician and Silurian Rocks

The Ordovician Period is currently regarded as having extended from about 495 to 443 million years ago. The Silurian Period is believed to have extended from 443 to 418 million years ago.

Ordovician and Silurian rocks in Great Britain

The Ordovician and Silurian rocks found in Great Britain were deposited mostly within a deep ocean, known to geologists as the Iapetus Ocean. This ocean lay between two huge continents which, during Ordovician and Silurian times were rapidly converging. Thick layers of mud accumulated on the ocean floor, together with substantial amounts of muddy sands, deposited from vigorous turbidity currents carrying sediment from the adjoining continental shelves. Enormous crustal stresses, resulting from the movement of the two continents, caused widespread subsidence of the ocean basins, substantial volcanic and other magmatic activity and repeated deformation of the sediments deposited. As the continents eventually collided, destroying the Iapetus Ocean early in Silurian times, the muds were eventually compressed to form hard mudstones and slates; the muddy sands were compacted to form the sandstones we know today as greywackes.

Great Britain's Ordovician and Silurian rocks are important on a regional, national and international level. As the original, or 'type', areas for these two geological periods, the British Ordovician and Silurian successions remain important standards for the description and interpretation of rocks of these periods throughout the world.

Ordovician and Silurian rocks in the AONB

The Ordovician and Silurian rocks of the AONB are considered together in this document as they share many geological similarities and occur closely associated in small, rather complexly faulted exposures. Their outcrop occupies only 221 hectares or 0.1% of the surface area of the AONB, but hosts the type localities for several Ordovician and Silurian fossils.

The most extensive outcrops of these rocks occur along the foot of the North Pennine escarpment where, as a result of uplift along the Pennine Fault System, they are exposed beneath the Carboniferous rocks which make up the greater part of the North Pennines. This belt of Ordovician and Silurian rocks is generally known by geologists as the Cross Fell Inlier. A variety of rock types within this area can be correlated with similar rocks of the Lake District, notably parts of the Ordovician Borrowdale Volcanic and Dent groups, and the Silurian Windermere Supergroup.

Outcrops of Ordovician rocks, believed to be equivalent to the Skiddaw and Borrowdale Volcanic groups of the Lake District, are exposed beneath basal Carboniferous rocks in the Teesdale Inlier.

Elsewhere in the AONB and adjoining areas, Ordovician and Silurian rocks are known to occur at depth beneath younger rocks and have been proved beneath the Carboniferous rocks in a small number of boreholes. The North Pennines may be regarded as a platform composed mainly of Ordovician and Silurian rocks, upon which Carboniferous rocks have been deposited.

In order to name, map and interpret the rocks formed during intervals of geological time, geologists subdivide the succession of rocks into individually recognisable Formations which comprise rocks with physical and perhaps chemical, features that distinguish them from other formations. Two or more geographically associated formations with notable features in common may be combined in a Group, which in turn may be further combined within a Supergroup.

Period	Group		Formation	Main Rock Types
SILURIAN	WINDERMERE SUPERGROUP		Brathay	Dark bluish grey, laminated graptolitic mudstones and siltstones with sporadic calcareous nodules
SILURIAN	WINDERMERE SUPERGROUP	Stockdale	Browgill	Pale greenish grey unfossiliferous mudstone with a few thin black graptolitic mudstone beds, succeeded by red mudstone
SILURIAN	WINDERMERE SUPERGROUP	Stockdale	Skelgill	Dark brown to black shaly or blocky mudstones
ORDOVICIAN	WINDERMERE SUPERGROUP	Dent	Ashgill Formation	Calcareous mudstone with beds and lenses of decalcified limestone; shelly fauna
ORDOVICIAN	WINDERMERE SUPERGROUP	Dent	Swindale	Mid-grey calcareous mudstones, with bands and lenses of greenish grey fine grained limestone commonly decalcified at outcrop to brown rottenstone
ORDOVICIAN	WINDERMERE SUPERGROUP	Dent	Dufton Shale	Dark grey, partly calcareous siltstones and mudstones, with thin bands or lenses of silty limestone
ORDOVICIAN		Borrowdale Volcanic	Harthwaite	Volcanic sandstone and siltstones and tuffs
ORDOVICIAN		Borrowdale Volcanic	Knock Pike	Lapilli-tuff and tuff
ORDOVICIAN		Borrowdale Volcanic	Studgill	Lapilli-tuff and volcaniclastic sandstone
ORDOVICIAN		Skiddaw	Kirkland	Mudstones interbedded with many thick bands of tuff (volcanic ash) and lavas
ORDOVICIAN		Skiddaw	Murton	Siltstones and mudstones with some sandstones
ORDOVICIAN		Skiddaw	Catterpallot	Siltstones and interbedded sandstones

The currently accepted classification of the Ordovician and Silurian rocks of the AONB is shown in the table above.

"Keisley Limestone Quarry, Dufton". © S. Clarke, BGS, NERC.

• Ordovician Rocks

Within the AONB, the earliest Ordovician rocks comprise sedimentary rocks closely resembling, and of the same age as, the Skiddaw Group rocks of the Lake District.

The Kirkland Formation contains mudstones interbedded with many thick bands of tuff (volcanic ash) and lavas and gives a lithological sequence quite distinct from that of the wholly sedimentary Murton and Catterpallot formations. Graptolites within the mudstones have enabled identification of the Kirkland Formation as having been deposited during a period of volcanic activity that pre-dated the Borrowdale Volcanic Group (BVG).

At Pencil Mill, at the foot of Cronkley Fell in Teesdale, soft, pale coloured slightly metamorphosed slates, crop out within the Teesdale Inlier. Rare graptolite fossils collected from these rocks confirm their correlation with the Skiddaw Group slates of the Lake District.

The Skiddaw Group rocks were folded, uplifted and eroded before the accumulation of tuffs and volcanic sandstones of the Studgill, Knock Pike and Harthwaite formations. These are the equivalent of the thick succession of lavas and volcanic sediments, known in the Lake District as the Borrowdale Volcanic Group (BVG). Within the AONB outcrops of BVG rocks are confined to several small, mainly fault-bounded blocks along the foot of the North Pennine escarpment, together with a tiny isolated outcrop in the banks of the River Tees at the foot of Cronkley Fell.

All of these Ordiovician rocks were further folded and eroded before being submerged by a shallow sea in which the Dent Group (formerly known as the Coniston Limestone Group) formed. It would be difficult to subdivide the relatively monotonous series of limestone, mudstone and siltstones were it not for the rich variety of shelly fossils that provide a detailed biostratigraphy.

The lowest part of the Dufton Shale Formation between Millburn Beck and Roman Fell is known as the 'Corona beds' after the commonly occurring brachiopod *Trematis corona*.

At the top of the Ordovician succession in the AONB, the Keisley Limestone, in and around Keisley quarry, is the best example of an Ordovician carbonate mudbank in England. It has yielded a varied range of shelly fossils, including trilobites.

"Knock Pike and Dufton Pike". © B. Young, BGS, NERC.

• **Silurian Rocks**

During the Silurian Period mudstones and siltstones were deposited in rather deeper waters than those of late Ordovician times. Within the AONB outcrops of Silurian strata are restricted to heavily faulted ground along the foot of the North Pennine escarpment. Graptolite fossils, found in these rocks, enable correlation with the Lake District and Howgill Fells, and show that a considerable, if not complete, sequence of these rocks is present in the AONB.

The oldest beds of the Skelgill Formation lie at the entrance to Keisley Quarry. Younger beds are seen in isolated exposures in Great Rundale Beck and Swindale Beck, Knock. The lower part of the Browgill Formation is exposed in Swindale Beck.

The Brathay Formation is exposed in Swindale Beck and also downstream from Keisley Bridge.

Impact on the landscape

The distinctive landscape of the Cross Fell Inlier reflects the varied nature of the exposed Ordovician and Silurian rocks. Most distinctive and conspicuous are the steep-sided rather conical hills, such as Knock Pike and Dufton Pike, which mark the outcrops of Ordovician volcanic rocks. These are topographically more reminiscent of the landscape associated with the equivalent rocks of the Lake District than of the typical North Pennines hills.

The Ordovician slates and volcanic rocks of the Teesdale Inlier are almost everywhere concealed beneath a substantial mantle of glacial deposits and have comparatively little direct effect upon the area's landscape.

Impact on biodiversity

Limestones outcrops, such as the Keisley Limestone, support a flora similar to that of the Carboniferous limestones of the North Pennines. Outcrops of other rocks within the Cross Fell Inlier are commonly partly mantled by glacial or later deposits. In these areas the natural vegetation is characteristic of much of the outcrops of other non-calcareous rocks of the North Pennines.

Economic use

A variety of Ordovician and Silurian rocks have been worked in small quarries in the Cross Fell Inlier. Keisley Quarry produced limestone for burning in kilns and stone for local use.

Other quarries, such as Knock Pike Quarry, yielded volcanic rock for use as road stone. The soft Skiddaw Group slates exposed at Cronkley Mill, in Upper Teesdale, were formerly worked for the making of slate pencils, known locally as 'Widdies'.

There are no quarries currently working the area's Ordovician and Silurian rocks.

Wider importance

Although these rocks occupy a comparatively restricted surface outcrop within the AONB, they include a variety of rock types representative of significant parts of the British Ordovician and Silurian successions. These rocks provide important evidence of the Ordovician and Silurian geology of both Europe and North America.

The AONB includes the type localities for several Ordovician and Silurian fossils.

Conservation issues

Several individual sites are currently protected as SSSIs (see below). Monitoring of their condition by, or on behalf of, English Nature should ensure that they are conserved in a condition appropriate to their importance as geological features. Other exposures of these rocks within the AONB are not currently perceived to be subject to any significant threats, apart from those normally associated with natural outcrops and stream sections.

Currently protected sites of Ordovician and Silurian rocks within the AONB

SSSI NAME	GCR NAME	GRID REF
Harthwaite Sike	Harthwaite Sike	NY702 247
Keisley Quarry	Keisley Quarry	NY714 238
Melmerby Road Section	Melmerby Road Section	NY623 383
Pus Gill	Pus Gill	NY696 256
Swindale Beck	Swindale Beck	NY688 275

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

RIGS

Knock Pike, Flagdaw NY687285

Durham County Geological Sites

Pencil Mill, Lunedale NY848296

Selected references:

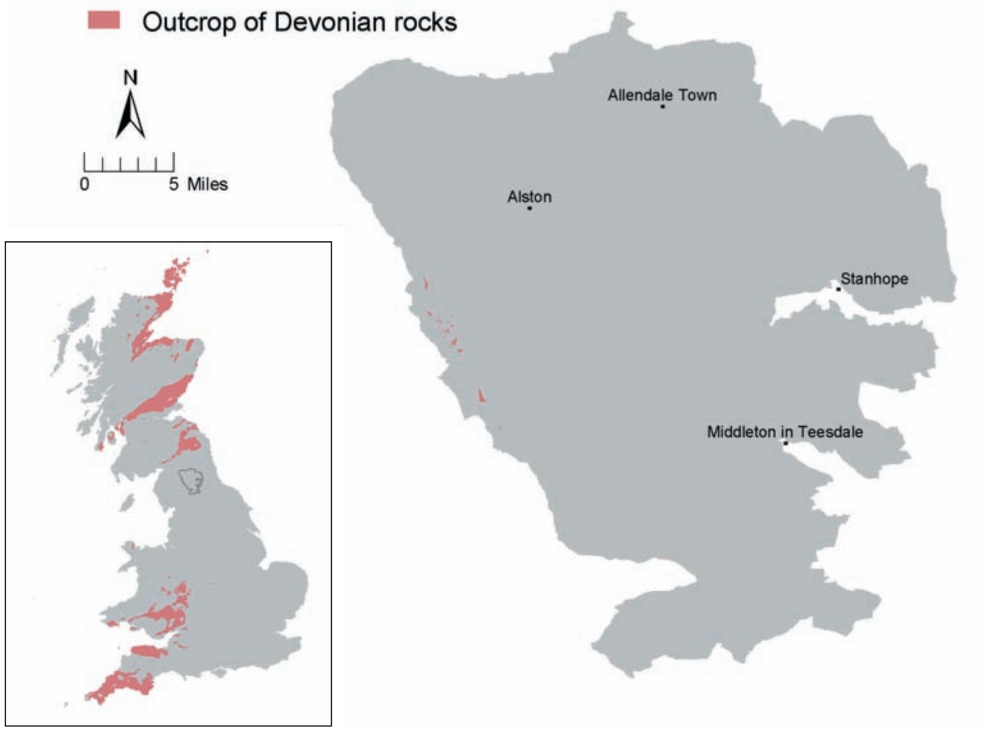
Arthurton and Wadge, 1981; Burgess and Wadge, 1974; Burgess and Holliday, 1979; Dunham, 1990; Rushton, Owen, Owens and Prigmore, 1999: Stone et al, 2010.

Devonian Rocks

Devonian rocks were formed during the episode of Earth history known as the Devonian Period between approximately 409 and 363 million years ago. The name 'Devonian' is derived from Devon, where rocks of this age were first recognised and studied.

Devonian rocks in Great Britain

In Devon and Cornwall, Devonian sedimentary rocks comprise a thick succession of mudstones and some limestones which yield fossils giving clear evidence of deposition in marine conditions. Elsewhere in the Great Britain, Devonian sedimentary rocks most commonly comprise thick sandstones, mudstones or conglomerates which are typically red or reddish brown in colour. These rocks are commonly referred to as 'Old Red Sandstone', to distinguish them from the 'New Red Sandstone', a succession of rocks of similar appearance and origin, formed during later Permo-Triassic times. The Old Red Sandstone rocks are believed to have been deposited mainly under desert conditions. Fossils are generally very rare, though beautifully preserved fish fossils in some of these rocks in parts of Scotland suggest the local presence of large lakes. Igneous rocks of Devonian age in Great Britain include a variety of lavas, notable examples of which include those in the Cheviot Hills and Central and Western Scotland.



Devonian rocks in the AONB

Outcrops of rocks assigned to the Devonian Period occupy only 65 hectares, or 0.03%, of the surface area of the AONB. These rocks closely resemble the Old Red Sandstone rocks seen elsewhere in Great Britain . A series of conglomerate, known in older geological literature as the 'Polygenetic Conglomerate', crop out at several places on the lower part of the North Pennine escarpment. They are composed of blocks, up to 1 metre across, comprising a variety of rock types, including slates, volcanic rocks and microgranites, typically embedded in a purplish red sandy matrix. The included rock types are recognisable amongst the Ordovician rocks of the Lake District and Cross Fell Inlier, from which areas they were almost certainly derived.

Because fossils have not been found in these rocks their age cannot be established with certainty. However, by comparison with other areas, and in view of their geological setting, they are generally considered to be of Devonian age.

These rocks are of extremely limited extent and are known from only a handful of very small outcrops along parts of the lower slopes of the North Pennine escarpment.

Exposure of the 'polygenetic Conglomerate' near Melmerby. © B. Young, BGS, NERC

Impact on the landscape and biodiversity

Because of their extremely limited outcrop Devonian rocks have little impact upon the landscape and biodiversity of the AONB.

Economic use

Devonian rocks are not known to have had any economic use within the AONB.

Wider importance

Despite their very limited outcrop, and although they cannot be conclusively shown to be of Devonian age, these rocks are of importance in understanding both the geological history of northern England and the area's place in the geological evolution of Great Britain.

Conservation issues

The very limited outcrops of Devonian rocks appear robust and there are not currently perceived to be any threats to their integrity.

Currently protected sites of Ordovician and Silurian rocks within the AONB

The single exposure of these rocks within the AONB is not afforded any statutory protection.

Other representative sites in the area

Melmerby Beck and field track NY6280 3705 – NY6287 3704

Selected references:

Arthurton and Wadge, 1981; Burgess and Wadge, 1974; Stone et al, 2010.

CARBONIFEROUS ROCKS

Carboniferous rocks formed during the Carboniferous Period of Earth history, between approximately 354 and 290 million years ago. The first use of the term Carboniferous was in Britain and derives from the abundance of carbon-rich coal seams within these rocks.

Carboniferous rocks In Great Britain

Global continental movements initiated towards the end of the Devonian Period resulted in a general north-south extension of the earth's crust beneath the area now occupied by Britain. This produced a series of 'basins' separated by 'highs' or 'blocks' and caused the sea to flood much of the area which had been land at the end of Devonian times. In the early Carboniferous, the 'block and basin' topography resulted in the deposition of thick marine shale successions in the 'basins' and thin shallow-water limestone sedimentation on the 'blocks'. Some areas, such as the Southern Uplands and an area of upland that extended from what is now Wales, across eastern England into Belgium, and known to geologists as the Wales-Brabant High (or St George's Land) remained above the transgressing tropical sea. The blocks were separated from adjacent basins by hinge lines. These were fault zones along which movement occurred intermittently during sedimentation. Continued earth movements throughout Carboniferous times led to differential subsidence and uplift, with successive periods of flooding and emergence causing a cyclic pattern of sedimentation.

As long ago as the 18th Century, three main divisions of Carboniferous rocks, based predominantly on rock type, were recognised: Carboniferous (or Mountain) Limestone, Millstone Grit and Coal Measures. Whereas this early nomenclature has been substantially modified, the broad threefold division remains largely valid with Carboniferous time commonly divided into three time intervals or series, named in ascending order the Dinantian, Namurian and Westphalian. These correspond very approximately with the Carboniferous Limestone, the Millstone Grit and the Coal Measures.

Carboniferous rocks in the AONB

With an outcrop area of 18,6545 hectares, or 94% of the surface area, Carboniferous rocks comprise by far the most widespread group of rocks within the AONB.

The currently accepted classification of the Carboniferous rocks of the AONB, together with the equivalent obsolete terms found in older literature, is shown in the table opposite.

Whereas the names of individual beds of, for example, the Tynebottom Limestone, the Firestone Sandstone or the Little Limestone 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 two decades, has led to a fundamental revision of the naming of Carboniferous strata over wide areas, including the North Pennines. This new nomenclature, which is intended to enable easier correlation of these rock sequences with their counterparts elsewhere in Great Britain and beyond, and to simplify national nomenclature, will be employed on future editions of British Geological Survey maps and in the technical Earth science literature.

However, as this terminology has yet to appear widely outside of the specialised technical literature, the stratigraphical nomenclature used in this audit is that employed on currently available 1:50 000 scale geological maps of the British Geological Survey. The new names applicable to subdivisions of the Carboniferous rocks of the AONB are indicated in the two right hand columns of the table.

<table>
<tr><th>Old-fashioned terms</th><th colspan="2">Modern Chronostratigraphical divisions</th><th>Divisions used on existing 50k geological maps and this document</th><th colspan="2">Divisions likely to be used on maps and descriptions of the area in the future</th></tr>
<tr><td>Coal Measures</td><td rowspan="5">Upper Carboniferous</td><td rowspan="2">Westphalian</td><td rowspan="2">Coal Measures</td><td rowspan="2">Coal Measures</td><td rowspan="2"></td></tr>
<tr><td rowspan="3">Millstone Grit</td></tr>
<tr><td rowspan="3">Namurian</td><td>Stainmore Group</td><td>Stainmore Formation</td><td rowspan="4">Yoredale Group</td></tr>
<tr><td rowspan="2">Great Limestone</td><td rowspan="3">Alston Formation</td></tr>
<tr><td rowspan="6">Carboniferous (or Mountain) Limestone</td></tr>
<tr><td rowspan="5">Lower Carboniferous</td><td rowspan="5">Dinantian</td><td rowspan="2">Alston Group</td></tr>
<tr><td>Robinson Limestone</td><td rowspan="4">Great Scar Limestone Group</td></tr>
<tr><td>Melmerby Scar Limestone</td><td rowspan="3">Melmerby Scar Limestone Formation</td></tr>
<tr><td>Orton Group</td></tr>
<tr><td>Basement Group</td></tr>
</table>

Before looking in detail at the main subdivisions of Carboniferous rocks in chronological order, and in order to appreciate some of the features of these rocks present throughout the Carboniferous sequence, we will review briefly some of the most characteristic features, including the main rock types or lithologies, present in the area's Carboniferous rocks.

In common with much of the British Carboniferous, a conspicuous feature of the Carboniferous succession of rocks in Northern England is a cyclicity or regular repetition of rock types. Periodic change between marine and fresh water or fluviatile conditions allowed the deposition of the well developed and laterally extensive cycles of sedimentation (cyclothems) for which the region is famous. The cyclicity can be observed at a variety of scales and in varying degrees of complexity. The largest cyclothems occur at the scale of tens to hundreds of metres in thicknes. The term 'Yoredale cyclothem' is commonly applied to these repeated successions of Carboniferous rocks after the old name – Yoredale – for Wensleydale in the Yorkshire Pennines where they were first studied in detail. Such Yoredale cyclothems typically comprise, in upward succession limestone, shale , sandstone, seatearth and coal.

The key characteristics of the main rock types present within the AONB's Carboniferous rocks are summarised as follows:

The formation of Yoredale Cyclothems. © Elizabeth Pickett/NPAP

• **Limestones**

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

• **Mudstones, Shales And Siltstones**

Dark to medium grey mudstones, commonly referred to as shales where they exhibit well-marked lamination, comprise a substantial part of the Carboniferous succession, particularly in the Namurian and Westphalian parts of the sequence . With an increase in silt content they pass imperceptibly into siltstones. Both mudstones and siltstones may contain fossils of marine or fresh water origin, depending on their environment of deposition. Indeterminate plant fragments are common in many freshwater mudstones and siltstones. Especially prominent are fossilised rootlet traces in original growth position in mudstone or siltsone beds which are known form their origins as the fossilised soil beds beneath coal seams as 'seatearths'.

Because they are usually weak and weather easily, these rocks are seldom well exposed except in rapidly eroding stream banks of in some quarry faces.

• Ironstones

These occur at several horizons, mostly within the Namurian and Westphalian successions. Most common are concentrations of clay ironstone nodules, composed mainly of impure siderite, within beds of mudstone. An unusual oolitic ironstone, containing the iron silicate mineral chamosite, and known as the Knuckton Ironstone, is present locally in the Hunstanworth area.

• Sandstones

The area's sandstones exhibit a considerable variation. The great majority are fine- to medium-grained rocks, although much coarser, locally pebbly, sandstones are present in places. The sandstones vary from hard, resistant rocks with a well-developed cement, to comparatively weak, in some instances almost friable rocks, where only a weak cement is present. Cross bedding is extremely common and ripple marks are conspicuous locally. Many sandstones provide clear evidence of erosive bases, clearly betraying their origins as the fillings of channels. Erosion surfaces within individual sandstone units are common. Well-preserved fossils are generally uncommon, though casts of marine brachiopods, bivalves and crinoids locally reveal a marine origin. More commonly, certain sandstones exhibit recognisable rootlet traces, or other plant remains, clearly indicative of their origins in a well-vegetated fresh-water or swamp environment. Such sandstones comprise fossil soils or 'seat earths', and may be overlain by a thin coal seam or a very bituminous parting representing the remains of abundant vegetation. It is common for such sandstones to be significantly richer in silica than many of the other sandstones, and for silica to be the major cementing mineral in the rock. These extremely hard silica-rich rocks are commonly known as 'ganisters'.

"Namurian shales in old ironstone workings" © B. Young, BGS, NERC.

• Coals

Coals occur throughout the Carboniferous succession of the AONB, though they are thickest and most abundant within the Westphalian beds. A feature of the coals of the North Pennines is their 'rank'. 'The rank' of a coal is its degree of maturity. The effects of temperature and pressure over long periods of geological time tend to expel water and volatile constituents from coal. Therefore a coal which has been subject to elevated temperatures typically exhibits a comparatively low votalile content, high carbon content and high calorific value. The coals of the North Pennines are generally of high rank and may be described as semi-anthracite. Their rank is a result of the heating effects of the concealed Weardale Granite.

• Cherts

Very fine-grained siliceous rocks, called cherts, are present within the lower part of the Namurian succession in the southern part of the AONB.

Naming the Carboniferous rocks

It was the practice of miners and quarrymen to give local names to the rock units, with which they became extremely familiar, particularly the limestones and many of the sandstones. Most of these names were applied at an early date and were adopted by the emerging science of geology where they became formalised as names for rock units. They may reflect a variety of intrinsic characteristics, for example:

- The **Four Fathom** and **Five Yard** limestones reflect typical thicknesses of those units, 24 feet (7.3 m) and 30 feet (9.1 m) respectively.
- The **Scar Limestone** reflects its role in giving rise to landscape features.
- The **Great Limestone** reflects both its thickness and economic importance as a source lime or as a host for mineral deposits.
- The **Melmerby Scar, Peghorn** and **Tyne Bottom** limestones derived their names from the localities where these units are best developed.

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

- **Hazle** (pronounced hezzle) means sandstone
- **Sill** usually refers to sandstone, or in some instances (e.g. the Coal Sills) a comparatively discreet group of beds consisting predominantly of sandstone.
- **Flagstones** are typically hard sandstones which tend to split readily along, or parallel with, the bedding planes. They may contain thin shale partings which facilitate this splitting.
- **Grit** usually refers to a hard, coarse-grained sandstone, commonly one with a proportion of comparitvely softer grains which ensures that the rock maintains a rough surface when exposed to wear in millstones.
- **Plate** refers to shales and silty shales.

Dinantian Rocks

Dinantian rocks were formed during the Dinantian Epoch of the Carboniferous Period, between approximately 327 and 316 million years ago. The name Dinantian is taken from the Belgian town of Dinan, where there are good sections in the limestone cliffs of the River Meuse.

Dinantian rocks in Great Britain

Sedimentary rocks make up the bulk of the Dinantian succession, although volcanic rocks are present locally in the English Midlands, Cumbria, north Northumberland and southern and central Scotland. Over much of Britain, the pattern of Dinantian outcrops reflects deposition within the pattern of fault-bounded blocks and basins, which characterised the Carboniferous. The Carboniferous Dinantian successions of northern England generally comprise cyclic repetitions of marine limestones alternating with deltaic mudstones and sandstones. Much greater thicknesses of sediments accumulated within the basins than on the intervening blocks, though widespread marine limestones enable correlation between basins and blocks. Although the succession of Dinantian rocks varies considerably from area to area, across much of northern Britain the rocks record a progressive change from thick marine limestones to the highly characteristic repeated sequences known as Yoredale cyclothems.

Dinantian rocks in the AONB

Outcrops of Dinantian strata cover 55,997 hectares in the central and western areas of the AONB. Because of their general easterly regional dip, the oldest beds crop out in the west and are succeeded eastwards by progressively younger beds.

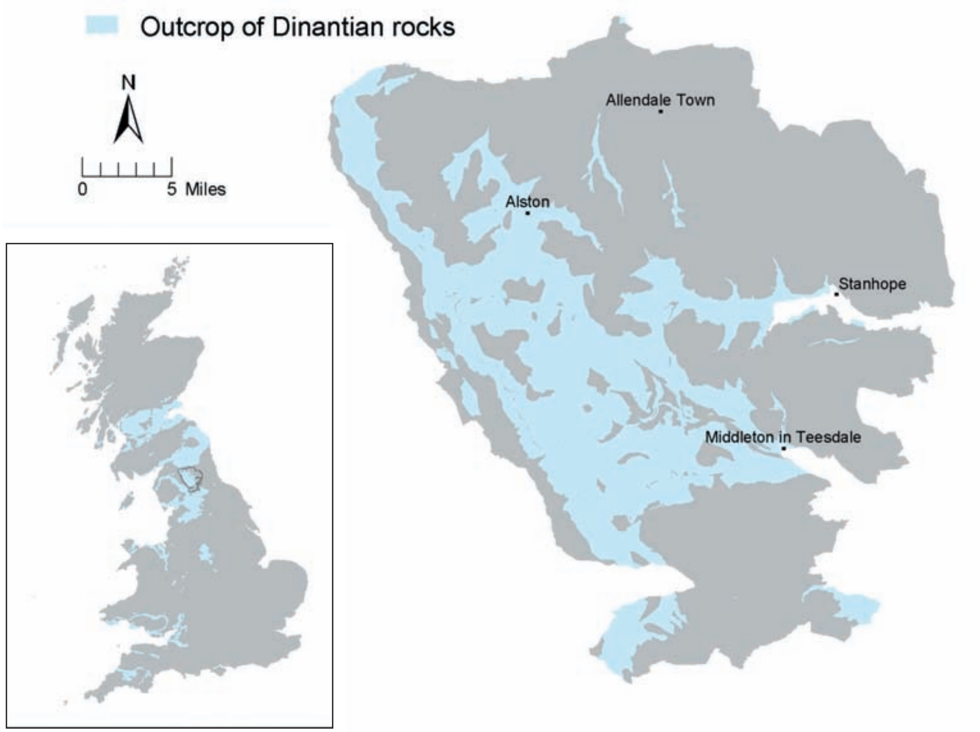
As discussed above, the classification of the Dinantian rocks of the AONB, adopted in this document, is based on that used in currently available 1:50000 scale geological maps.

• Basement Group

The Basement Group comprises the first Carboniferous sediments deposited, following a period of erosion in the Devonian Period. These rocks rest unconformably upon older rocks. The lowest part of the Group consists predominantly of conglomerates composed of fragments of Ordovician and Silurian rocks, overlain by sandstones and shales, a few bands of impure limestone and, rarely, thin coals. The thickness of the strata varies as the sediments filled irregularities in the underlying surface. Outcrops of the Basement Group rocks are restricted to the North Pennine escarpment and the Teesdale Inlier at the foot of Cronkley Fell

The Basement Group may be subdivided as follows:

- Roman Fell Sandstones
- Roman Fell Shales
- Basal Conglomerate



• Orton Group

The Orton Group is poorly exposed, mainly on the North Pennine escarpment. The group generally consists of about 30m of interbedded dark grey limestones, mudstones and sandstones. The Group is most completely developed in the Brough area, where it may be divided into the following units:

- Hillbeck Limestones
- Ashfell Sandstone
- Ravenstonedale Limestones

• Alston Group

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

"Falcon Clints, Teesdale. Conglomerates and shales of the Orton Group". © B. Young, BGS, NERC.

be traced across the whole area. The thickest limestone unit within the AONB is the Melmerby Scar Limestone. Of the rock types within this succession, limestones are the most widespread and consistent in composition and thickness. Apart from the Melmerby Scar and Robinson limestones, which are typically pale grey, the limestones are mostly medium to dark grey in colour. Between the limestones, the succession of rock-types, mainly comprising mudstones and sandstones, is much more varied in character and thickness from place to place. Immediately above the limestones, the shales are locally fossiliferous and calcareous. They typically pass upwards into dark grey or black mud rocks, in places with clay-ironstones. Although several of the more prominent sandstones can be traced over large areas, their thickness may vary markedly and in places the sandstone may be absent. The top of the sandstone unit may be a seatearth with abundant rootlet traces and a strong siliceous cement, giving the distinctive rock known as 'ganister'. Coal, if present, is rarely more than a few centimetres thick. In addition to the limestones, all of which were named at an early date by miners and quarrymen, many of the most persistent sandstones were also named. Only one shale unit, the Tynebottom Plate, has acquired a widely used name.

Impact on the landscape

The extensive outcrop of Dinantian rocks within the AONB has a profound influence on the landscape. Weathering of the alternately hard and soft beds within the Yoredale cyclothems has produced a highly distinctive terraced form to many of the hillsides. Limestones and many sandstones are typically resistant to erosion, compared to interbedded shales and softer sandstones. These hard beds thus tend to be expressed as steeper slopes, in places marked by small rocky scars; softer beds give rise to more gentle slopes or areas of 'slack' ground. In numerous streams and rivers, waterfalls mark the outcrop of many of the harder limestones and sandstones. Good examples include Ashgill Force, Summerhill Force (alternatively known as Gibson's Cave) and Nent Force. These commonly provide excellent exposures of complete or nearly complete cyclothems.

The extensive low-angle slopes that lie to the east and north-east of Cross Fell reflect the gently inclined beds of Dinantian rocks. Wide outcrops of the Melmerby Scar and Robinson limestones on the escarpment in the Melmerby and Brough areas, give rise to crags and locally some areas of limestone pavement. Lines of sinkholes typically mark the position of many of the area's limestone outcrops and are well developed on the Melmerby Scar Limestone (see Karst).

In contrast with the rest of the Dinantian rocks, the lowermost part of the succession, the Basement Group and the Orton Group, have more limited impact on the landscape where they form the lower slopes of the escarpment.

Many miles of drystone walling, which are such a distinctive feature of the landscape, are built from locally quarried Dinantian sandstones. The pattern of improved pastures and fields, so characteristic of the North Pennine dales, owes much to the use of slaked lime produced from locally quarried Dinantian limestones.

Impact on biodiversity

As with their effect upon the landscape, the Dinantian rocks exert a fundamental influence on the area's biodiversity. Bare limestone crags and pavement provide extremely important habitats for a number of specialised plant communities, including lichens and other lower plants. Elsewhere, outcrops of limestone, where free, or substantially free, of superficial cover, typically support areas of limestone grassland. The comparatively brighter green, more species-rich, vegetation on the limestone, compared to the rather sombre vegetation of the more acidic soils developed on the intervening shales and sandstones, is often a conspicuous landscape feature visible from some distance and may be a useful clue to identifying limestone outcrops. Carboniferous limestones, where exposed as cliffs tall enough to exclude grazing sheep, provide refugia for plants such as alpine conquefoil, roseroot and rare grass species. Some cliffs support nesting sites for birds such as peregrine and raven. Caves and enlarged joints within natural outcrops and quarries locally serve as important bat roosts.

Outcrops of shales or sandstones, where substantially free of superficial cover, typically support a range of neutral to acidic soils upon which neutral to acid grassland vegetation is characteristic.

Economic use

Dinantian rocks have been of considerable economic significance within the AONB.

The outcrops of most of the limestones are marked by small quarries and associated kilns, formerly worked to provide local supplies of quicklime and slaked lime for use as a soil improver. Extraction of limestone from the Robinson Limestone at Helbeck Quarry, Brough, and the Great Scar Limestone at Hartley Quarry, Kirkby Stephen, continues today. Many of the Dinantian

"Hilton Mines, Scordale. Crags of Whin Sill overlying Melmerby Scar Limestone". © B. Young, BGS, NERC.

sandstones have been employed as building stones, mostly for very local use. Substantial amounts of locally produced sandstone have been employed in drystone walling. The Dinantian rocks comprise important host rocks for metalliferous veins and associated replacement deposits. Only a few coals in the Alston Group have ever been worked.

Wider importance

The North Pennines AONB includes some of the best and most complete examples of 'Yoredale' cyclothems to be seen in Great Britain. Comparison of this area with adjacent sedimentary basins, such as those of the Solway, Midland Valley and Craven basin, allows correlation of rock units to further understanding of the UK's evolution during Carboniferous times.

Conservation issues

Whereas most of the exposures of these rocks and features associated with them, in natural exposures and abandoned quarries, are robust elements in the landscape, suitable vigilance should be exercised to ensure that no operations or activities damage the most important of these features. The progressive deterioration of long-abandoned quarry faces, together with risks of quarries being filled, may pose some long-term threats.

Currently protected sites of Dinantian rocks within the AONB

SSSIs

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

RIGS

Punchbowl Bridge, North Stainmore	NY3008 5128

Durham County Geological Sites

Black Cleugh, Burnhope	NY853394
Bow Lees Beck	NY907283
Green Gates Quarry,	NY 934236
Horsley Burn Waterfall, Eastgate	NY975384
Middlehope Burn,	NY906381
Killhope Burn, Copthill Quarry and Wear River at Butreeford Bridge	NY855406
Killhope Lead Mining Centre	NY823433
Scoberry Bridge to Dine Holm Scar	NY910274
Sedling Burn, Cowshill	NY855405
Stanhope Burn	NY987398
Widdybank Fell	NY820290

Other representative sites in the area

Ardale Beck	NY661349
Ashgill Force, Garrigill	NY758405
Cow Green, Upper Teesdale	NY813307
Falcon Clints, River Tees	NY830284
Summerhill Force (Gibson's Cave), Bowlees	NY910287
Knock Ore Gill	NY701300
Knott Quarry, Cow Green	NY818309
Wildboar Scar	NY682323

Namurian Rocks

Namurian rocks were formed during the Namurian subdivision, or Epoch, of the Carboniferous Period known as the Namurian, between approximately 327 and 316 million years ago. The name Namurian is derived from the province of Namur in Belgium.

Namurian rocks in Great Britain

Within Great Britain almost all rocks of Namurian age are sedimentary. Over substantial areas of the central and southern Pennines and the Peak District, Namurian rocks mainly comprise thick successions of hard, coarse-grained sandstones to which the term 'Millstone Grit' is commonly applied, from the suitability of many of its sandstone beds for making grindstones. In the North Pennines and Cumbria, Namurian rocks typically comprise thick successions of shales, siltstones and sandstones with some, generally thin, beds of limestone and coals.

The broad pattern of 'troughs' and 'blocks'which was established during Dinantian, times persisted into the Namurian. The Namurian rocks of northern England reveal evidence of the transformation from the predominantly marine conditions of the Dinantian, to the almost exclusively fresh water deltaic environments of the Westphalian.

Namurian rocks in the AONB

Namurian rocks crop out over 124,583 hectares, or over 63%, of the AONB.

These rocks have extensive outcrops in the north, east and south of the area and form much of the higher ground of Alston Moor, Weardale and the northern side of Teesdale. Particularly conspicuous are the exposures of Great Limestone in the numerous large abandoned quarries in Weardale.

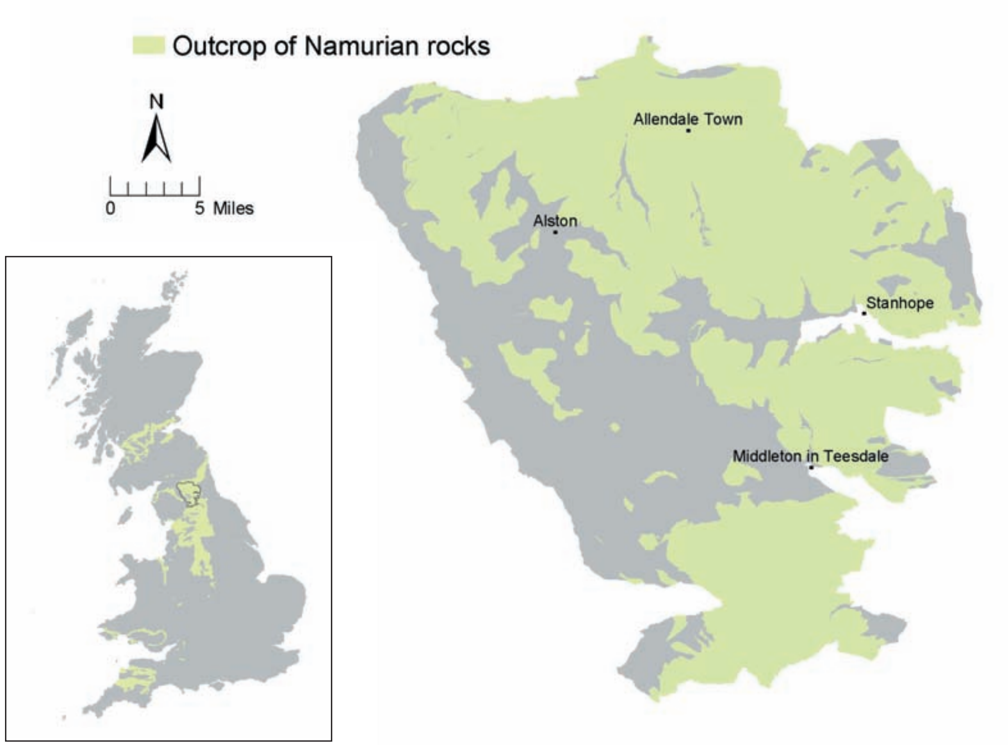
As discussed above, the classification of the Namurian rocks of the AONB, adopted in this document, is based on that used in currently available 1:50000 scale geological maps.

• Stainmore Group

In the North Pennines, the lowest unit of Namurian age is the Great Limestone.

The Great Limestone, up to 22 metres thick in the Stanhope area, is one of the thickest limestones within the Carboniferous succession of the North Pennines. Like the majority of the underlying Dinantian limestones, the Great Limestone typically comprises a medium-grey, slightly bituminous limestone, in which small fragments of crinoids are usually common. However, it also contains a number of distinctive beds which can be traced throughout much of the AONB and beyond.

- The ***Chaetetes Band*** occurs commonly within 1 – 2 metres of the base of the limestone. It is a bed, in places up to around 1 metre thick, in which superbly preserved encrusting mats of the sponge *Chaetetes depressus*, accompanied by colonial corals and a variety of brachiopods, bivalves etc., are preserved in growth position. Although very conspicuous in many localities this bed is absent at others.
- The ***Brunton Band*** is a bed rich in microscopic algae which occurs locally around 5 metres above the base of the limestone.



- The ***Frosterley Band*** is widely present around 6 to 7.5 metres below the top of the limestone. It is rarely more than 0.5 metres thick and is distinguished by containing variable, but often abundant, concentrations of the solitary rugose coral *Dibunophyllum bipartitum*. The bed, which can locally be extracted in large slabs, takes a high polish. Under the name of ***Frosterley Marble*** it was commonly worked as an ornamental stone (see **Frosterley Marble,** below).
- The term ***'Tumbler Beds'*** is applied to the beds which form the uppermost approximately 4.5 metres of the Great Limestone. These comprise well-marked 'posts' of limestone separated by beds of dark grey shale up to 0.6 metres thick and are named from their troublesome instability during mining or quarrying.

Apart from the Great Limestone at its base, the Stainmore Group comprises rhythmic alternations of mudstones, siltstones and sandstones with only a few thin limestones and some very thin coals. Mudstones and siltstones make up the greater proportion of the succession, though they are seldom well exposed. The sandstones exhibit the characteristics of typical Carboniferous sandstones described above; many provide clear evidence of erosive bases. The very large cast of a tree stump and associated root system, preserved today in Stanhope churchyard, is a particularly spectacular example of a plant fossil from a 'seat-earth' sandstone.

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

The limestones commonly exhibit a rather characteristic soft, brown, earthy weathering to which the term 'famp' is locally applied. Towards the top of the Namurian succession limestones become fewer and much more impure, locally becoming difficult to distinguish from calcareous sandstones or mudstones.

Although most of the coals are very thin, usually a few centimetres thick at most, and impersistent, the Little Limestone Coal is locally up to about 2 metres thick.

Ironstones, typical of the clay ironstones described above, occur at several horizons within the Namurian succession. More unusual ironstones, which seem not yet to have been described in the geological literature, include the distinctive oolitic **Knuckton** and **Rookhope ironstones.**

Impact on the landscape

These rocks are of fundamental importance in shaping the landscape and giving it its distinctiveness. The Great Limestone is well exposed in the sides of many of the valleys and along the North Pennine escarpment. It typically forms distinctive pale grey rocky scars or low crags, partially clothed in limestone grassland, which commonly contrasts strikingly with the more acid vegetation on the overlying rocks. In common with other limestones, the Great manifests a number of features characteristic of limestone country, collectively known as 'karst' (see **Karst Features,** below). The Great Limestone supports one of the AONB's few examples of a typical limestone pavement, near Brough. Prominent lines of 'sink' or 'shake' holes clearly mark the top of the Great Limestone along many hillsides. As one of the thickest of the area's limestones, the Great has been extensively quarried; abandoned quarries, which expose the limestone and its overlying beds, are conspicuous features in the landscape of Weardale around Stanhope and Frosterley. The Great Limestone's role as a host for mineral veins has also impacted significantly on the area's landscape.

Above the Great Limestone, rocks of the Stainmore Group underlie much of the open moorland which typifies much of the AONB. Much of the outcrop of Namurian rocks is substantially free of any significant cover of superficial deposits, though spreads of hill peat are widespread in places. Weathering of the flat-lying, or very gently inclined, mainly shale/sandstone succession has produced extensive areas of rolling moorland with comparatively few natural exposures of rock, except in deeply incised streams. Differential weathering of the more resistant sandstones and intervening shales has produced prominent terraced hillsides on which sandstone (and locally thin limestone) outcrops, form steep-sided terrace features. In places where the rock is especially resistant, low grey-weathering sandstone crags occur. Some of the limestones locally give rise to low scarp features. Elsewhere the nature of the underlying rock is betrayed by scattered blocks in the soil, or in small pits and quarries opened to provide local sources of stone for the many miles of drystone walls which are such distinctive elements in the enclosed landscapes of these dales. The summits of Cross Fell and other peaks along the North Pennine escarpment and on Alston Moor are formed of characteristically flat cappings of Namurian sandstones. Sandstone beds give rise to the prominent crags which rim the summit of Cross Fell.

"Chaetetes Band, River Nent, Nenthead Mines". © D. Millward, BGS, NERC.

"Characteristic terraced hillside, Blagill, Nent Valley." S.Clarke © BGS, NERC

Impact on biodiversity

Much of the impact of the Namurian rocks is similar to that of the Dinantian rocks.

Small areas of limestone pavement, for example at Palliards near Brough, provide one of the AONB's finest examples of this internationally scarce habitat. Extensive quarrying of the Great Limestone has left a legacy of abandoned quarries which exhibit varying degrees of degradation and regeneration and are commonly hosts to a rich limestone flora. Although the other limestones within the Stainmore Group have much smaller outcrops than the Great, and have been much less frequently quarried, small exposures of these rocks locally provide habitats similar to those associated with the Great Limestone.

However, the bulk of the Stainmore Group comprises shales and sandstones which typically weather to a range of mainly acidic soil types. The wide outcrops of these rocks are distinguished by expanses of moorland vegetation, including some fine examples of heather moorland, though management and grazing regimes have resulted in the widespread development of pale coloured Nardus grassland.

"Middleton Common. Heather moorland on outcrop of Namurian Rocks". © Charlie Hedley, Countryside Agency.

Economic use

By far the most important economic product of the Namurian succession has been limestone. Almost certainly, every limestone unit within the AONB provided local supplies of limestone for the making of quicklime and hydrated lime as a soil improver, obtained from countless small quarries and associated kilns scattered across the area. However, limestone production assumed large-scale industrial proportions during the late 19th and 20th centuries when huge quarries in the Great Limestone of Weardale supplied limestone for use as a flux in the iron and steel plants at Consett and elsewhere in the adjoining Durham Coalfield. In addition, limestone from the Great and other limestone formations became an important source of crushed rock aggregate, for building and road making. The demand for limestone flux ended some time ago and many of the area's limestone quarries have long been abandoned. However, the Great remains a major source of crushed limestone products from Broadwood and Heights quarries in Weardale.

The Frosterley Marble, a distinctive coral-rich bed within the Great Limestone, is known to have been worked as an ornamental stone for use in Durham Cathedral and elsewhere as early as the 14th Century and has been worked intermittently ever since (see **Frosterley Marble** below). However, the amounts produced over this long period of working are likely to have been very small.

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

Almost all of the sandstones within the Stainmore Group have found local use in drystone walls and farm buildings. Many have been worked for building, paving and roofing stones and for making setts. The names of some of these units give important clues to their properties and local uses. The Grindstone Sill provided material for grindstones, the Slate Sills commonly offered flaggy sandstones suitable for roofing slabs, the Firestone Sill was locally used as a source of hearth stones. At the time of writing (January 2010), small workings for building and paving stone are active at the following sites:

Baxton Law, Hunstanworth	NY 932 468
Dead Friars, Stanhope	NY 969 453
Flinty Fell, Nenthead	NY 771 417
Leipsic, Alston	NY 735 504
Mousegill Bridge, North Stainmore	NY 857 115
Dodd Fell, Allenheads	NY 864 459

Siliceous sandstone, or ganister, for making refractory products, has been worked from a number of the sandstones. The most extensive of these workings are in the sandstones considered to be part of the Coalcleugh Beds, at Harthope Quarries at Harhope Pass, Weardale.

Several of the Namurian coal seams have been worked, both for local domestic use and as an important fuel for lead smelting. The most extensive workings have been in the Little Limestone Coals, particularly at the Ayle, Blagill, Baraugh, Clargill and Flow Edge collieries near Alston. Conspicuous lines of spoil heaps mark the sites of abandoned workings along the outcrops of the Little Limestone Coals, particularly in the Nent and South Tyne valleys. Similar characteristic dark grey heaps of waste shale mark the sites of workings in the Coalcleugh Coal and in other more minor seams.

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

Wider importance

The North Pennines AONB includes some of the most extensive outcrops of Namurian rocks in the UK. Comparing and contrasting the detailed nature of individual rock units and the overall succession within the AONB with adjoining areas, is vital to understanding the complex history of the UK's evolution during Carboniferous times. The Great Limestone marks the last significant episode of limestone formation in the Carboniferous succession. It contains abundant evidence of the contemporary marine fauna and flora and in places, e.g. in the Frosterley and *Chaetetes* bands, exhibits striking examples of complete marine ecosystems fossilised *in situ*. Namurian sandstones in the AONB contrast both lithologically and in their environment of deposition, from the classic 'Millstone Grit' of the central and southern Pennines. They therefore provide important evidence of the varied environments prevailing in northern Britain during Namurian times.

Threats

Many of the exposures of the AONB's Namurian rocks and features associated with them, are robust elements in the landscape. However, suitable vigilance should be exercised to ensure that no operations or activities pose threats to these features. Numerous abandoned quarries expose important sections through parts of the Namurian succession. The progressive deterioration of long-abandoned quarry faces, together with the risk of quarries being filled, poses some long-term threats. The face at Greenfield Quarry, Weardale, has been damaged by fossil hunters and research workers.

Currently protected sites of Dinantian rocks within the AONB

SSSIs

SSSI NAME	GCR NAME	GRID REF
Botany Hill	Botany Hill	NY955 204
Grag Gill	Grag Gill	NZ026 235
Rogerley Quarry	Rogerley Quarry	NZ019 375
Sleightholm Beck Gorge 'The Troughs'	Sleightholm Beck Gorge 'the Troughs'	NY965 116

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

RIGS

Bank's Gate, North Stainmore

Howhill Quarry, Alston

Nenthead, Alston Moor

Durham County Geological Sites

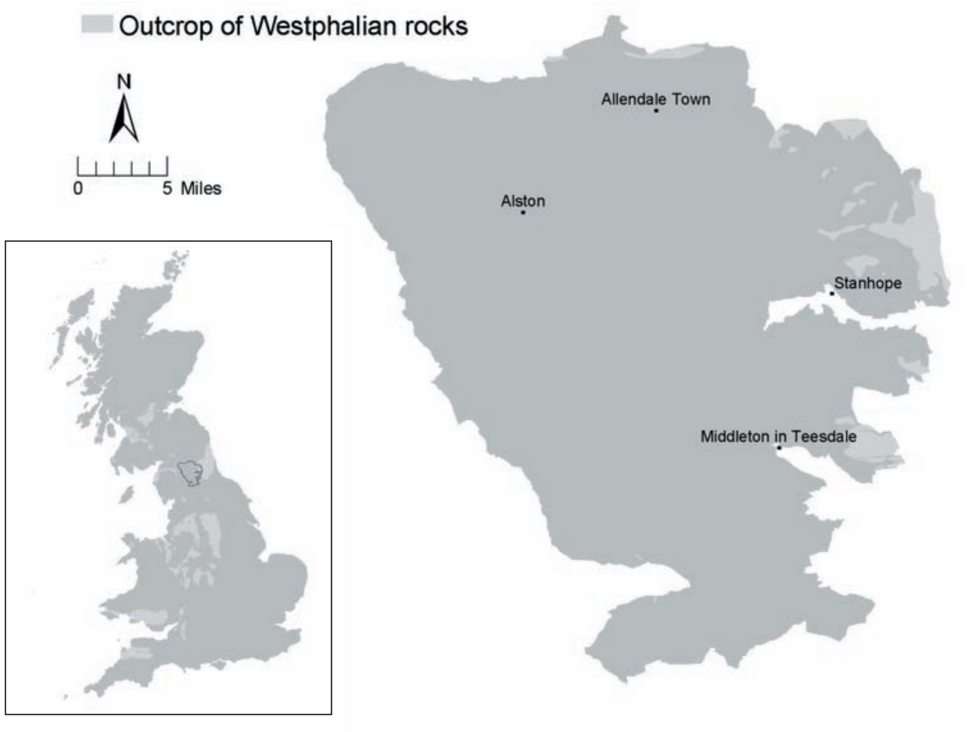
Chestergarth Quarry, Rookhope	NY943418
Derwent River Gorge,	NZ090530 – NZ050497
Fine Burn, Bollihope	NZ023351
Greenfield Quarry, Cowshill	NY851422
Harehope Quarry, Frosterley	NY038367
Harthope Quarry, St John's Chapel	NY863352
Harthope Head Quarries, St John's Chapel and Langdon Beck	NY864339
Middlehope Burn,	NY906381
Killhope Lead Mining Centre	NY823433
Roundhill Quarry, Stanhope	NZ011383
Stanhope Burn	NY987398
Sedling Burn, Cowshill	NY855405
Spurlswood Beck and Quarter Burn, Eggleston	NZ022268
Stable Edge Quarry, Newbiggin	NY919282
Teesdale Cave (Moking Hurth Cave)	NY868310

Other representative sites in the area

River Nent, Nenthead Mines Visitor Centre	NY785 431 – NY788 427
River Allen gorge, Allenbanks	NY800 592 – NY799 640
River West Allen, Carrshield	NY803 465
Beldon Burn	NY916497
Coal Crag, Nookton Burn	NY923472
Croglin Water	NY615476
Forest Head Quarries, Hallbankgate	NY584574
Harthope Bank Quarry, Langdon Fell	NY864339
Hartleyburn Common & Glendue Fell	NY637550
Hudeshope Burn	NY936308
Stanhope Burn, Stanhope	NY956442

Westphalian Rocks

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



Westphalian rocks in Great Britain

In Great Britain Westphalian rocks are most commonly known as the 'Coal Measures'. These rocks typically consist of repeated cyclical successions of sandstones, siltstones and shales with numerous coal seams and associated fossil soil beds, or 'seatearths'. In addition to the great abundance of economically important coal seams, the Coal Measures also locally contain important deposits of sedimentary iron ores and clay. The Coal Measures therefore comprise one of the most economically significant parts of the British geological succession.

The Coal Measures rocks of Great Britain were deposited as sediment within a series of large delta complexes in discrete basins, separated by barriers which formed areas of non-deposition and sometimes erosion. The rivers building the deltas deposited thick beds of sand, silt and mud. Equatorial forests of huge primitive trees, ferns and other vegetation flourished on swampy delta slopes. Thick deposits of peat, derived from the partial decay of this vegetation, accumulated from time to time on this surface and, when buried and compacted beneath further layers of sediment, became the coal seams we see today. Repeated subsidence and rebuilding of the deltas resulted in the deposition of cyclic sequences of rocks, reminiscent of the 'Yoredale' successions of earlier Carboniferous times, though without beds of limestone. The typical order, in upwards succession, in which the main rock types follow one another within the Coal Measures is: coal, mudstone, siltstone, sandstone, seatearth, coal (of the next cycle above).

Because of their economic importance, and in order to exploit their coal reserves most efficiently, it was important to be able to correlate these coal-bearing rocks between different coalfields. In the absence of many distinguishing features within the coals themselves, two types of 'marker' beds have long been of importance in correlation. These are marine bands and tonsteins. ***Marine bands*** are thin layers of sediment deposited during discrete marine incursions formed during periods of high world sea level. They are present over very wide areas and contain characteristic fossil assemblages, so that they have become the primary means of correlation within and between coalfields. ***Tonsteins*** are mudstones rich in the clay mineral kaolinite, which are thought to have originated as layers of fine airborne volcanic dust. They typically occur as thin beds in coal seams and have proved important for establishing correlations in continental Europe.

The Westphalian rocks are normally divided into a number zones based on fossils. Five main groups of fossils have been used: goniatites (ammonoids), conodonts, non-marine bivalves, miospores and plants.

Carboniferous swamp. © Elizabeth Pickett

Westphalian rocks in the AONB

The AONB includes parts of the western extremity of the Durham Coalfield, together with small outliers of Coal Measures rocks along the line of the Stublick Fault System in the Tyne Valley and associated with the Pennine Fault System in the Brough area of Cumbria. Westphalian rocks occupy an outcrop area of 5,963 hectares (3%) of the surface area of the AONB. The Westphalian rocks of the Durham and adjacent coalfields were laid down in a single depositional basin, which occupied an upland area corresponding closely to what is today the Southern Uplands of Scotland High and another Carboniferous upland area that extended from present day Wales to Belgium, and known to geologists as the Wales-Brabant High.

Only rocks of the Lower Coal Measures (Westphalian A) are present within the AONB. In the east, the lowest beds of the Coal Measures are exposed at the westernmost edge of the Durham coalfield. In the north, portions of the Midgeholme, Plenmeller and Stublick coalfields, small faulted outliers of Coal Measures rocks, fall within the AONB and in the south-west the AONB includes portions of the small Stainmore Coalfield, near Brough.

The Midgeholme, Plenmeller and Stublick coalfields are mostly elongated east-west and consist of southward-dipping Coal Measures rocks which terminate abruptly against faults to the south. The faults form part of the Stublick-Ninety Fathom fault system, an important regional structural lineation, and were exposed during the excavation of the Plenmeller Opencast Coal site.

• Lower Coal Measures Rocks

Traditionally the base of the Coal Measures (Westphalian) in County Durham was taken at the Ganister Clay Coal, considered to be the lowest workable coal. This no longer accords with palaeontological evidence from other coalfields in Britain and north-west Europe, where the base of the Coal Measures is defined by a marine band containing the goniatite *Gastrioceras subcrenatum.* This fossil has yet to be found in north - east England, but in its absence the base of the Coal Measures in north - east England is now taken at the position of Quarterburn Marine Band, which is exposed in Quarter Burn, near Hamsterley. The rocks between Quarterburn Marine Band and the Ganister Clay Coal contain only thin and sporadic coals and are characterised by a high proportion of sandy strata. In older geological literature they were referred to collectively as the Third Grit, of the old 'Durham Millstone Grit Series', thereby emphasising the similarity between this part of the Coal Measures and the highest beds of the underlying Namurian.
A marine band at the top of this 'Third Grit', known as the Roddymoor Marine Band, can be seen in Spurlswood Beck. Coals thicker than 0.9m and most of the productive seams are largely confined to the beds above the Brockwell Coal. Below the Brockwell seam sandstones tend to be coarse and some are siliceous enough to be called ganister.

Traditionally, each colliery applied its own set of seam names. This led to much confusion. Thus, not only were individual seams given numerous local names, but, where the same name was used in different collieries it was commonly applied to different coals. Eventually, standard sets of names and index letters were established for County Durham and Northumberland combined. It is now accepted that these largely hold good throughout the main coalfield, but different names have been used in the outlying areas. The National Coal Board (NCB) developed a series of standard index letters for each seam as a means of aiding and standardising correlation within and between coalfields. The table below indicates the names and index letters of the seams present in the Lower Coal Measures of the main Durham Coalfield and the equivalent names applied in the Plenmeller and Stublick areas in the north of the AONB.

Impact on the landscape

The soft and thinly bedded sandstones, shales and coals of the Coal Measures generally give rise to gently rounded convex slopes. Occasional thicker sandstone beds are marked by steeper bluffs. Small becks and burns drain the upper valleys, occasionally incised in narrow gills. Soils are typically heavy and seasonally waterlogged.

County Durham	Plenmeller	Stublick	County Index letter applied by British Coal
Tilley	Bounder		P
Top Busty	Upper Craig Nook	Upper Craig Nook	Q or Q1
Bottom Busty	Lower Craig Nook	Upper Craig Nook or Five Quarter	Q2
Three Quarter	Little	Little	R
(not named)	Three Quarter	(not present)	
(not named)	Half	Three Quarter	
Top Brockwell	Quarter	Quarter	S or S1
Bottom Brockwell	Well Syke or Coom Roof	Well Syke or Main	
Victoria Fish Bed	High Main	High Main	S/T
Victoria	Slag or Seven Quarter	Slag (or little)	T
Marshall Green	Low Main	Low Main	U
Ganister Clay			V

"Plenmeller Opencast Coal Site in 1980's". © B. Young, BGS, NERC.

Impact on biodiversity

Over moorland parts of the AONB, Westphalian rocks support a vegetation pattern, which is extremely similar to that found on the Namurian rocks above the Great Limestone. On poorly drained ridges and plateaux, peaty gleys and deeper peats have formed, supporting heathland vegetation of heather, bilberry and acid grassland.

Economic use

No mining in Westphalian rocks within the AONB is now taking place, but evidence of previous mining activity is seen in pit-fallen land, abandoned shafts and adits and several spoil heaps. Of the various areas mined, those at Stublick and south of Plenmeller are the most significant. Records of coal working near Midgeholme appear in the household book of Lord William Howard in 1618 and the colliery has additional fame as, after it's use as a ballast engine, Stephenson's Rocket was sold for use in the colliery. Opencast extraction also took place at Plenmeller in the late 1980's and early 1990's. Although coal has been extensively worked from the Coal Measures of County Durham over many centuries, the county has comparatively few workable seams within the boundaries of the AONB. In the south of the area, the Brockwell (S) and Busty (Q) seams were worked along Arn Gill from a series of adits and shafts in the Woodland area indicate that coal may have been worked there. At the north east tip of the AONB the Victoria (T) coal was worked just south of Rowley from Victoria colliery and opencast extraction from two leaves of the underlying Brockwell (S) seam took place in the same area during the 1940s and 1950s.

Coal Measures mudstones and seatearths were commonly worked as brick-clays, as by-products of coal mining. It is likely that 'common' bricks were produced from such materials at the collieries in the Tyne Valley. Coal Measures sandstones are important building stones in the AONB.

Wider importance

Exposures of Westphalian rocks within the AONB are insignificant by comparison with the extensive coastal sections of Northumberland, though there are some good natural and quarry exposures in the lower part of the succession. The AONB does, however, include the type locality of the Quarterburn Marine Band, the important horizon adopted as marking the base of the Coal Measures in north east England. On the northern margin of the AONB, the Westphalian outliers are important as examples of fault-bounded coalfields within northern England and help to define and demonstrate the geological structure of the area. The buildings at Stublick Colliery are one of the best surviving groups of 19th Century colliery buildings in the country.

Conservation issues

Whereas most of the few exposures of these rocks and features associated with them, in natural exposures and abandoned quarries, are robust elements in the landscape, suitable vigilance should be exercised to ensure that no operations or activities damage the most important of these features. The progressive deterioration of long-abandoned quarry faces, together with risks of quarries being filled, may pose some long-term threats. The fine group of colliery buildings at Stublick Colliery deserves protection.

Currently protected sites of Dinantian rocks within the AONB

SSSIs

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

RIGS

There are no RIGS sites within the AONB.

Durham County Geological Sites

Spurlswood Beck and Quarter Burn, Eggleston	NZ022268

Other representative sites in the area

Quarterburn, Hamsterley	NZ0170267
Clough Plantation Sand Pit	NZ111380
Quarry Wood Quarries	NZ074421
Greenfield Quarry	NZ096410

Selected references

Arthurton and Wadge, 1981; British Geological Survey, 1992, 1996; Burgess and Holiday, 1979; Burgess and Wadge, 1974; Cleal and Thomas, 1996; Dunham, 1990; Dunham and Wilson, 1985; Henderson and Lelliot, 1978; Johnson, 1958, 1970, 1995; Johnson and Dunham, 1963; Mills and Hull, 1976; Scrutton, 1995; Stone et al, 2010; Turner, 1999; Trotter and Hollingworth, 1932.

Permo-Triassic Rocks

Permo-Triassic rocks formed during the two episodes of Earth history known respectively as the Permian and Triassic periods. The Permian Period is generally assumed to have extended from around 295 to 245 million years ago and the Triassic Period from 245 to 208 million years ago. Despite these being clearly defined periods of Earth history, in many parts of Britain it is difficult to define precisely the boundary between the rocks formed in them. In such places, including the AONB, it is common practice to refer to these rocks collectively as of Permo-Triassic age.

The Permian Period takes its name from the Perm area of Russia, where these rocks were first recognised. The Triassic Period is so called from the threefold division of the unit in Germany where these rocks have been studied in great detail.

Permo-Triassic rocks in Great Britain

Sedimentary rocks comprise by far the greatest proportion of Permo-Triassic rocks in Great Britain, though volcanic rocks and intrusive igneous rocks occur in Devon and in parts of southern Scotland.

During Permo-Triassic times, the area which eventually became Great Britain drifted progressively northwards through equatorial latitudes from its position close to the equator at the close of Carboniferous times.

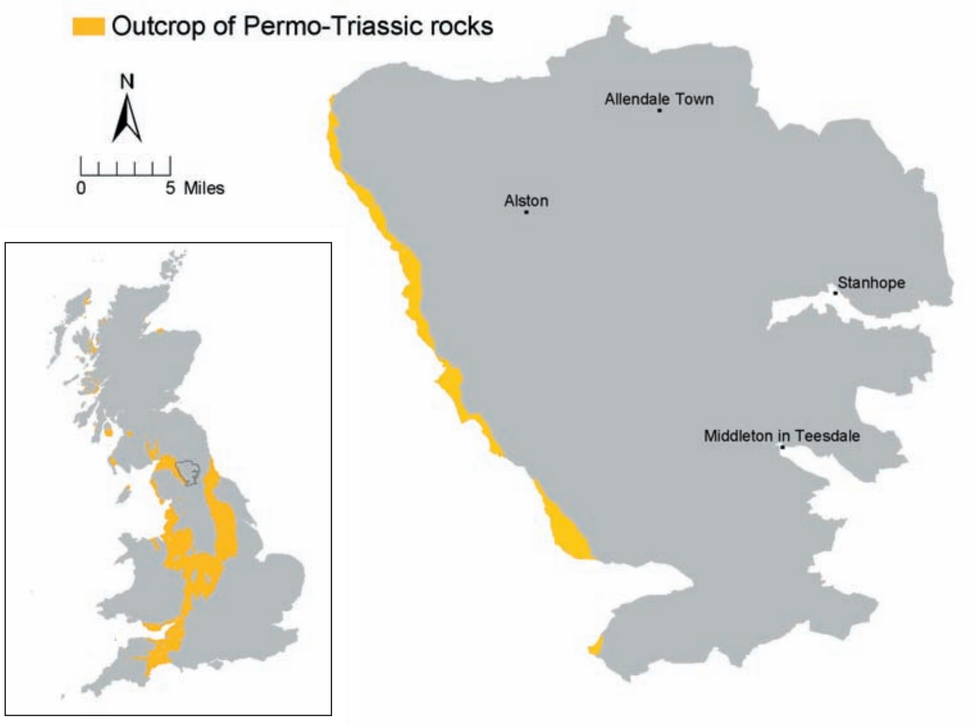
Uplift, folding and tilting of the Carboniferous rocks occurred in late Carboniferous and earliest Permian times, related to the effects of severe earth movements and mountain-building further south in what is now continental Europe. This converted much of this area into a landmass which suffered considerable erosion. This was initially a hot, arid desert, in which coarse broken rock and scree accumulated close to hill and mountain ranges, with widespread wind-blown sand dunes on the intervening plains. During Triassic times, vast thicknesses of sand, silt and mud accumulated over extensive coastal plains. We see these today as thick deposits of siltstones and mudstones, and sandstones.

Permo-Triassic rocks in the AONB

Outcrops of Permo-Triassic rocks comprise 4,688 hectares or 2.4% of the surface area of the AONB at the foot of the Pennine escarpment. They everywhere rest unconformably upon an eroded surface of Carboniferous and older rocks. The rocks beneath the unconformity typically exhibit reddening.

The main divisions of Permo-Triassic rocks (youngest at the top) are as follows:

- St Bees Sandstone (Sherwood Sandstone)
- Eden Shales
- Penrith Sandstone and Brockram



Penrith Sandstone and Brockram

The severe Earth movements, referred to above, at the close of Carboniferous and beginning of Permian times, uplifted the area we know today as northern England, creating mountains and hills in the areas today occupied by the Lake District and North Pennines. Lower land occupied the area of what is now the Solway Plain and Vale of Eden. The area was a hot, arid desert.

Rapid erosion of the newly formed mountains and hills resulted in thick accumulations of angular rock debris in great fans at the foot of the slopes. These are preserved today as the breccias and conglomerates known in Cumbria as the ***Brockram.***

Away from the immediate vicinity of the mountains and hills, and covering much of the lower ground, was a dry desert with huge wind-blown sand dunes, composed of coarse-grained sand. These sands are preserved today as the Penrith Sandstone, which exhibits features typical of desert sands such as rounded 'millet seed' grains and large-scale cross-bedding. Much of the Penrith Sandstone is pale brick red or salmon pink in colour due to small amounts of finely disseminated haematite.

• Eden Shales

These comprise beds of mudstone and siltstone, mostly of a dull red, or locally grey, colour.

The Eden Shales were formed as accumulations of mud and silt deposited within desert lakes or on the flood plains of rivers which crossed the desert. A bed of dolomitic limestone, present locally within the Eden Shales, is known as the Belah dolomite. The desert lakes periodically dried up, leaving beds of carbonate-rich mudstone and in places thick beds of rocks known as evaporites, which here comprise mainly gypsum or anhydrite.

The Eden Shales are weak, easily eroded rocks and there are typically few natural exposures. As the evaporite beds are very soluble in near-surface groundwaters, they have almost invariably been removed completely by natural dissolution and rarely crop out at the surface.

• St Bees Sandstone

Overlying the Eden Shales is a thick group of dull red sandstones, known in Cumbria as the St Bees Sandstone, after its spectacular development at St Bees Head in west Cumbria. The St Bees Sandstone is part of a very much more extensive deposit of sandstone which occupies wide areas of central England, where it is today generally known as the Sherwood Sandstone, taking its name from Sherwood Forest where it crops out widely. The St Bees Sandstone is much finer grained and is a duller, more brownish red colour than the Penrith Sandstone.

The St Bees Sandstone is interpreted as having been deposited on a wide alluvial plain crossed by numerous braided rivers. Fossilised rain-prints and desiccation cracks, preserved in the sandstone, reveal that at times the accumulating sands were exposed to drying out.

Outcrops are restricted to a very narrow belt of country along the foot of the North Pennine escarpment and comprise the extreme eastern edge of the Vale of Eden, much of which is floored by substantial thicknesses of Permo-Triassic rocks.

Impact on the landscape

The Permo-Triassic deposits of eastern Cumbria are mainly weak rocks, especially when compared with the more resistant rocks which form the main mass of the escarpment and North Pennine uplands. Differential erosion has resulted in the excavation of the Vale of Eden along their outcrop, between the North Pennine escarpment in the east and the mountains and foothills of the Lake District in the west. The harder, and comparatively more resitant Penrith Sandstone forms hilly country around Penrith, a short distance beyond the AONB.

The almost universal red colour of area’s Permo-Triassic rocks give rise to the characteristic red soils of the Vale of Eden. The extensive use of red sandstone, particularly the St Bees Sandstone, in vernacular architecture lends a distinctive character to the landscape, particularly in villages such as Croglin.

“St Bees sandstone in Croglin Quarry” Charlie Hedley © Countryside Agency

Impact on biodiversity

Over much of their comparatively restricted outcrop within the AONB, Permo-Triassic rocks are substantially concealed beneath a mantle of superficial, mainly Quaternary, deposits. Only in a few rather limited areas are these rocks exposed at the surface where they exert any direct influence on soil type, supporting very sandy, rather dry soils.

Within the AONB, the Penrith and St Bees sandstones are the most commonly exposed formations. In addition to a few natural exposures of these sandstones, mainly in stream sections and abandoned quarries, more substantial amounts are present in the built environment, providing substrates for a variety of moss and lichen communities.

Economic use

Both the St Bees and Penrith sandstones have been widely employed as building stone in the vernacular architecture of the East Fellside. In most cases stone has been obtained from small pits, sometimes opened to supply stone to the adjoining village or even in some instances to provide materials for a single building or farm.

The coarse-grained breccias and conglomerates of the Brockram have locally served as building stones in parts of the Vale of Eden. In places near Kirkby Stephen, immediately beyond the AONB, limestone-rich parts of the Brockram have, in the past, been quarried for lime burning.

Although gypsum and anhydrite beds within the Eden Shales are known to extend into the AONB, there are no records of any workings of these from the area, though both minerals are still worked in the Kirkby Thore area immediately beyond the AONB.

Wider importance

The Brockram and Penrith Sandstone, and their relationships to each other, offer clear insights into the rapid erosion of the newly formed mountains at the beginning of Permo-Triassic times and the nature of the arid desert conditions which prevailed at that time. The succeeding Eden Shales and St Bees Sandstone record the progressively changing environmental conditions during this period. Studies of the evaporite beds, and features associated with them, have contributed much to the understanding of these rocks elsewhere within Great Britain.

Conservation issues

Exposures of these rocks are mainly in small stream sections and abandoned quarries. Whereas most of these appear reasonably robust, the progressive deterioration of long-abandoned quarry faces, together with risks of quarries being filled, poses some long-term threat. There are not currently perceived to be any specific threats to the integrity of any exposures or features related to these rocks.

Currently protected sites of Permo-Triassic rocks within the AONB

SSSIs

Permo-Triassic rocks are exposed within a number of areas scheduled as SSSIs. However there are no sites within the AONB specifically designated for Permian or Trissaic rocks within the Geological Conservation Review.

RIGS

Croglin village Quarry	NY5757 4747
Frank’s Bridge, Kirkby Stephen	NY776 087

Other representative sites in the area

Milburn Beck,	NY6775 2860
Keisley	NY7123 2390
Gamblesby	NY6235 3888
Roman Fell	NY757 190
Hanging Walls of Mark Anthony	NY652 322
Fellside, Ousby	NY6327 3505
Crowdundle Beck, Blencarn	NY6600 3134 – NY6586 3138
Croglin	NY5758 4765 – NY5785 4816
Crowdundle Beck	NY6465 3061

Selected references

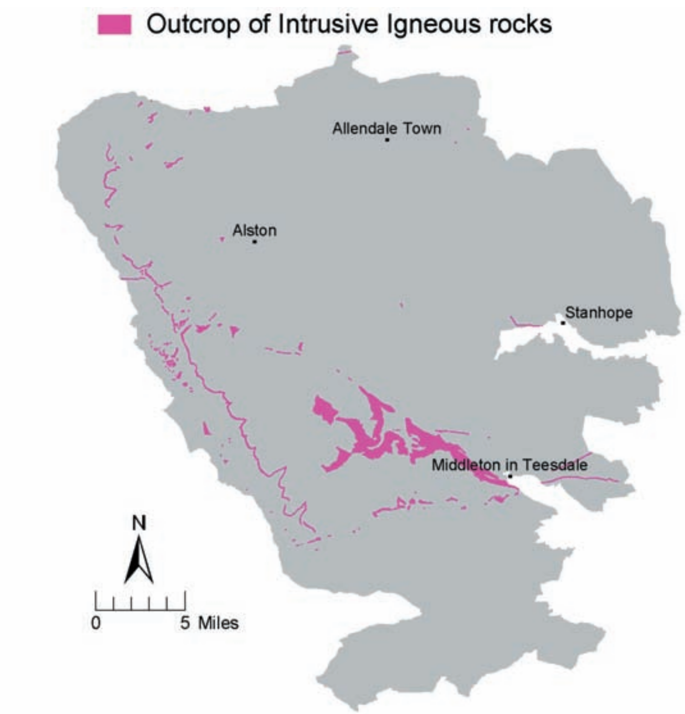
Arthurton and Wadge, 1981; Burgess and Holliday, 1979; Stone et al, 2010.

Intrusive Igneous Rocks

Intrusive igneous rocks formed by being intruded (emplaced) as molten rock, or magma, into the surrounding rocks. They are distinguished from volcanic, or extrusive igneous, rocks by having crystallised and cooled at depth within the Earth's crust. Such intrusions include widespread more or less horizontal sheets, known as sills; more or less vertical sheet-like bodies, known as dykes; and very large, often rather irregular, bodies known as batholiths.

Intruusive igneous rocks in Great Britain

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



Outcrops of intrusive igneous rocks, which range in composition from basalt and dolerite to granite, crop out over 3,200 hectares, or 1.6%, of the surface area of the AONB. One major intrusion, the Weardale Granite, does not reach the surface and has been proved only in the Rookhope and Eastgate boreholes. It has, however, played a major role in the geological evolution of the North Pennines over a long period of geological time. The intrusive igneous rocks of the area are reviewed briefly here according to their age of emplacement.

• Caledonian intrusions

These bodies of intrusive rock were emplaced during the long and complex series of Earth movements, known as the Caledonian Orogeny, which affected the area that was to become the UK, between roughly 500 and 390 million years ago. Within the AONB it is possible to recognise two groups of intrusive igneous rocks which date from this period:

• The Weardale Granite

The pattern of mineralisation in the Northern Pennines, and comparisons with areas such as SW England, together with geophysical evidence, suggested that a concealed granite may be present at depth. The Rookhope Borehole, drilled in 1960-61, proved granite at a depth of 390.5 metres. The granite was found to have a weathered top, proving it to pre-date the overlying Carboniferous rocks. Radiometric dating revealed its age of crystallisation of 410 ± 10 million years. Geophysical evidence suggests that the Weardale Granite is part of a very large concealed batholith which is likely to be some 60 by 25 kilometres in extent with several high spots, or cupolas, on its upper surface beneath Tynehead, Scordale and Rookhope. Like the Caledonian granite batholith that underlies the Lake District, it is possible that the Weardale Granite may be one of a number of separate, but related, granite intrusions, or plutons, that together comprise a North Pennine Batholith. The small intrusion of pink porphyritic microgranite, known as the Dufton Microgranite, within the Ordovician Dufton Shales of the Cross Fell Inlier, may be part of this batholith or may be part of a cupola arising from the roof of the Weardale Granite.

• Caledonian minor intrusions

The term 'minor intrusion' is applied to small bodies, or groups of small bodies, of intrusive igneous rock. Caledonian minor intrusions in the AONB include the lamprophyre dykes which cut the Ordovician Skiddaw Group mudstones at Pencil Mill, near Cronkley in Upper Teesdale and parts of the Cross Fell Inlier, and dyke and sill-like bodies of dolerite and pink felste, within the Skiddaw Group mudstones in the neighbourhood of Catterpallot, near Melmerby.

• Permo-Carboniferous basic sills and dykes - the Whin Sill Suite and its associated dykes

In late Carboniferous and early Permian times, deep-seated crustal stretching and fracturing allowed huge quantities of magma to rise from deep within the earth. In northern England this magma did not reach the surface, but spread widely as sheets between the layers of pre-existing rocks, where it cooled and crystallised. This extensive suite of intrusive igneous rocks is collectively termed the Whin Sill or the Great Whin Sill.

This complex underlies much of north east England, including most of the AONB. It typically comprises a series of widespread sills with some associated dykes and is composed of quartz-dolerite which exhibits a remarkable continuity in mineralogical and chemical composition across its extensive outcrop. By far the greater part of the complex consists of fine to medium-grained dolerite, though fine-grained rocks occur at the contact and very coarse-grained dolerite pegmatite veins and segregations occur locally. The sill reaches its maximum known thickness of around 70 metres in Teesdale and under parts of the Allen Valleys; it is significantly thinner on the North Pennines escarpment.

"Photomicrograph of thin section of Weardale Granite" © H. Emeleus, Durham University.

"High Force, Whin Sill overlying Tynebottom Limestone" – Diane Weston © Raby Estate.

Radiometric dating gives the Whin Sill an age of around 290 million years. Palaeomagnetic studies reveal that at the time of its crystallisation the area lay within tropical latitudes. Several dykes associated with the sill may have acted as feeders during its emplacement. Some of these have been given local names in the geological literature. These include the ***Haydon Bridge Dyke,*** the ***Greengates Dyke,*** the ***Connypot Dyke*** and the ***Hett Dyke.***

The intrusion of such huge volumes of molten dolerite at temperatures of around 1000°C had a profound effect on the surrounding rocks, resulting in widespread intense alteration, or metamorphism, with the formation of a variety of metamorphic minerals (see ***Metamorphic Rocks***). A variety of minerals which occur as joint linings within the sill, formed during the final phases of cooling.

Over much of the AONB the Whin Sill exists as a single, roughly horizontal, sheet. However, in the Rookhope and Stanhope area of Weardale, a much thinner upper leaf of the intrusion, known as the ***Little Whin Sill,*** is present. Both leaves of the sill were proved in the Rookhope Borehole.

The Little Whin Sill exposed in the abandoned Greenfoot Quarry, Weardale. © B. Young, BGS, NERC

• Palaeogene intrusive igneous rocks

During Palaeogene, or Tertiary times, Earth movements associated with the opening of the Atlantic, caused cracking of rocks in a radial pattern for many miles away from volcanic centres in what is today the Hebrides. As they developed deep beneath the surface, these cracks were filled with basaltic magma, forming a series, or swarm, of extremely long dykes. These may be traced across much of northern England, the most prominent being that known as the ***Cleveland-Armathwaite Dyke.*** These dolerite intrusions may be distinguished from those of the Whin Sill by their porphyritic character, with small phenocrysts of feldspar and pyroxene set in a dark grey fine-grained matrix. A minimum age of around 55 million years has been established for these rocks. Although these rocks have extremely small outcrops, they are the only rocks of Palaeogene age in the AONB.

"Crags of columnar jointed Whin Sill, Holwick Scar, Teesdale" © BGS, NERC.

Impact on the landscape

The buoyancy effect of the Weardale Granite within the basement rocks of the North Pennines has long influenced the geological history of the area throughout much of Carboniferous and later time. It is this continued buoyancy which partly accounts for the upland nature of the area today.

Because of its hardness and resistance to erosion, the outcrops of the Whin Sill comprise some of the area's best known and most dramatic landscape features. Most extensive and impressive are the Teesdale outcrops where it forms the sombre cliffs of Crossthwaite, Holwick and Cronkley Scars, as well as the waterfalls of High Force, Low Force and Cauldron Snout. On the North Pennine escarpment, where it is significantly thinner, it forms the rim to the spectacular rocky amphitheatre of High Cup Nick and lines of low grey crags in Scordale and elsewhere.

The Palaeogene dykes belonging to the Cleveland-Armathwaite Dyke suite, have extremely small outcrops and make little or no contribution to the landscape character of the AONB.

Impact on biodiversity

Where free, or almost free, of superficial cover, the Whin Sill typically gives rise to rather thin acid soils. These locally support populations of bell-heather, together with ling, bilberry, cowberry and some bearberry. The Whin Sill block screes may locally host parsley fern, which is a rarity on the east side of the Pennines.

Fissures between larger blocks of Whin Sill dolerite provide refuges for trees such as aspen, rock whitebeam and juniper, which represent relics of former woodland. At higher altitudes these blocks may provide habitats for arctic-alpine herbs.

Tall cliffs of Whin Sill provide nesting sites for a number of birds as indicated by the names Falcon Clints and Raven Scar: ring ouzels and wheatears may also be present.

Economic use

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

Very small amounts of rock from several of the ***Caledonian minor intrusions*** are incorporated into a few drystone walls, along with other locally available materials.

The hardness and roughness of the dolerite of the ***Great Whin Sill,*** the ***Little Whin Sill*** and associated dykes, makes these good sources of roadstone and aggregate, which have been worked in numerous quarries. Most conspicuous are those in the Great Whin Sill outcrops of Teesdale between Middleton and High Force. Force Garth Quarry, near High Force, is the sole remaining producer of Whin Sill dolerite in the AONB. Large tonnages of roadstone are produced here, mainly for use outside the AONB.

The ***Palaeogene dykes*** have not been worked within the AONB, except for extremely local use in farm walling, though they have yielded significant quantities of roadstone from quarries a few miles to the east.

Wider importance

The discovery of the pre-Carboniferous age for the Weardale Granite marked an important advance in understanding the geological evolution of northern England and led to substantial re-appraisals of the origins of ore genesis in this and comparable orefields worldwide. The buoyancy effect of the granite within the Lower Palaeozoic basement rocks of the North Pennines explains the persistence of the Alston Block as a positive feature throughout much of Carboniferous and later time.

The Whin Sill is regarded as the original 'sill' of geological science and therefore must be viewed as one of the key natural heritage features of the AONB. It takes its name from the north of England quarryman's term 'sill', meaning any generally horizontal body of rock, and 'whin' meaning a hard, intractable black rock. The recognition, in the 19th Century, of its intrusive origin, quickly led to the term 'sill' being adopted by geological science throughout the world for comparablel concordant horizontal intrusive bodies of this kind.

The Paleogene dykes give important clues to geological processes which operated far beyond the North Pennines.

Conservation issues

Natural exposures of these rocks within the AONB are generally robust and none appear to be under any threat. Abandoned quarries are at risk of becoming overgrown or degraded. Backfilling as landfill sites, or as part of other land reclamation schemes, may threaten to damage or destroy them. Whilst such activities are unlikely to occur in the AONB, sites should be monitored to ensure that important exposures are not lost.

Currently protected sites of Intrusive Igneous rocks within the AONB

SSSIs

SSS NAME	GCR NAME	GRID REF
Upper Teesdale	Whin Sill in upper Tees*	NY880 285

***These include:**

Cauldron Snout, Upper Teesdale	NY815 286
Force Garth Quarry (now known as Middleton Quarry), Upper Teesdale	NY873 282
High Force, Upper Teesdale	NY880 283
Low Force and Wynch Bridge, Teesdale	NY905 279
Falcon Clints, Upper Teesdale	NY820 281
Cronkley Fell	NY831 282 – NY854 282

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

Red Sike and Widdybank Fell, Upper Teesdale	NY818 296
Cow Green Reservoir, Upper Teesdale	NY815 294
Holwick and Crossthwaite Scars, Teesdale	NY898 271 – NY927 253
High Cup Nick	NY 745 262

RIGS

High Cup Nick	NY 745 262
Croglin waterfall	NY600 481

Durham County Geological Sites

Caledonian Minor Intrusions:

Cronkley Pencil Mill, Upper Teesdale	NY848 296

Great Whin Sill:

Greengates Quarry, Teesdale	NY934236
Horsley Burn Waterfall, Eastgate	NY975384
Killhope Burn, Copthill Quarry and Wear River at Butreeford Bridge	NY855406
Scoberry Bridge to Dine Holm Scar	NY910274
Widdybank Fell	NY820290
Wynch Bridge, Langdon Beck	NY820290

Other representative sites in the area

Caledonian Minor Intrusions:

Catterpallot Hill, Melmerby	NY6381 3621
Dry Sike, Melmerby	NY6399 3743
Melmerby Beck, Melmerby	NY6314 3688
Dufton Pike, Dufton	NY6930 2681

Great Whin Sill:

Middleton Quarry, Middleton in Teesdale NY947245

Closehouse Mine, Lunedale NY850227

River Tyne NY695629 - Haydon Bridge Dyke

River Lune, Lunedale NY813 207 - Connypot Dyke

Greengates Quarry, Lunedale NY933 234- Greengates Dyke

Wackerfield village NZ158 227 - Wackerfield Dyke

Eggleston Burn, Eggleston NY9857 2482 - Hett Dyke

Little Whin Sill:

Turn Wheel Linn, Rookhope Burn NY949 398

Palaeogene dykes:

Outberry Bat, Ettersgill, Teesdale NY8849 2955 - Cleveland-Armathwaite Dyke

Mirk Holm, Teesdale NY9086 2928 - Cleveland-Armathwaite Dyke

Smithy Sike, Teesdale NY8920 2950 - Cleveland-Armathwaite Dyke

Coldberry Gutter, Teesdale NY930 289 - Cleveland-Armathwaite Dyke

Eggleston Burn, Eggleston NY989 249 - Cleveland-Armathwaite Dyke

Selected references

Arthurton and Wadge, 1981; Burgess and Holliday, 1979; Dunham, 1990; Johnson, 1970; Mills and Hull, 1976; Stephenson, Bevins, Millward, Highton, Parsons, Stone and Weadsworth, 1999; Stephenson, Loughlin, Millward, Waters and Williamson, 2003; Stone et al, 2010; Trotter and Hollingworth, 1932

Metamorphic Rocks

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

In large areas affected by heat and pressure during mountain building, rocks may have suffered ***regional metamorphism.*** Adjacent to igneous intrusions rocks have commonly been affected by contact or ***thermal metamorphism.***

The nature and composition of metamorphic rocks reflect the intensity or grade of alteration. In most cases metamorphic rocks also reflect chemical and mineralogical changes resulting from the introduction of a variety of elements by permeating chemically reactive fluids, a process referred to as ***metasomatism.***

Metamorphic rocks in Great Britain

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

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

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

Metamorphic rocks in the AONB

The Ordovician and Silurian rocks which crop out along the foot of the North Pennine escarpment in the Cross Fell Inlier, and in the Teesdale Inlier, almost all exhibit evidence of low grade regional metamorphism. This is mainly the result of their involvement in earth movements and mountain-building events over millions of years. Metamorphism within these rocks has produced a number of new minerals within them, though the nature of the original rock is still evident in most cases.

Contact metamorphic rocks occur associated with many of the intrusive igneous rocks in the North Pennines. The largest single body of intrusive igneous rock is the wholly concealed Weardale Granite. A substantial contact metamorphic aureole must surround the granite, though direct evidence for this is limited. Signs of thermal alteration in the slates exposed in the Teesdale Inlier, and those penetrated in some deep boreholes, have also been interpreted as evidence of thermal alteration due to the Weardale Granite.

"Raft of altered sandstone in Whin Sill, Wynch Bridge, Teesdale." © S. Clarke, BGS, NERC

Contact metamorphism is particularly associated with the Whin Sill, especially in parts of Teesdale where a range of Dinantian rocks exhibit varying intensities of alteration, particularly in the Cow Green, Falcon Clints and Cronkley Fell areas. In places, high temperature metamorphism, almost certainly accompanied by the introduction of chemically active fluids (metasomatism) has altered mudstones and impure limestones to calc-silicate rich metamorphic rocks containing an abundance of minerals such as garnet, feldspar, chlorite, epidote, vesuvianite, diopside and magnetite. Wollastonite has been recorded from one locality. Elsewhere, shales may have been baked to a very fine grained hornfels or porcellanite, sometimes known to North Pennine miners and quarrymen as 'whetstone'. Purer limestones may have been recrystallised to coarse-grained marbles; the best known of these is that which developed from the Melmerby Scar Limestone, known locally from its highly distinctive crumbly weathering as 'sugar limestone.'

In the area between Scoberry and Wynch bridges in Teesdale, pyrite nodules in mudstones between the Cockleshell and Single Post limestones have been altered to pyrrhotite by the thermal effects of the sill. Also near Wynch bridge, a large xenolithic raft of sandstone, here recrystallised to a hard siliceous quartzite, occurs within the sill.

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

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

Whereas the most extensive, most intensely altered, and clearest exposures of contact metamorphic rocks associated with the Whin Sill are found in Upper Teesdale, rather similar, though mostly less intensely altered, limestones and mudstones are to be seen, mainly above the sill, on the North Pennine escarpment at the Hilton and Murton mines, near Appleby.

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

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

Impact on the landscape

Only in the Cow Green and Cronkley Fell areas of Teesdale do metamorphic rocks impose any perceptible characteristics on the landscape. In these areas the comparatively wide outcrop of the Melmerby Scar Limestone, here in the form of 'sugar limestone', is locally very well exposed, forming rather rounded, water-worn, pale grey outcrops. In some of these can be seen areas of crumbly disintegration producing a mineral soil largely made up of individual calcite crystals.

"Outcrops of 'Sugar Limestone' Widdybank Fell" © B. Young, BGS, NERC.

Impact on biodiversity

The presence of the metamorphosed Melmerby Scar Limestone and the included mudstones has had a most profound effect on the biodiversity of the North Pennines. This is most obvious in the vegetation. Base-rich, and in places unstable, Rendzina and Brown Calcareous soils have developed on exposures of 'Sugar Limestone' and on areas of glacial deposits rich in 'Sugar Limestone' debris. Where interbedded mudstones are exposed, and at the junction of the limestone with the top of the Whin Sill, base-rich gravelly flushes occur. These habitats support the 'Teesdale Assemblage' of rare plant species. This unique plant assemblage is considered to be a relic of the more widespread late-glacial and pre-forest-maximum flora that probably covered a much larger area of the North Pennine uplands during the wasting of the last ice sheets to occupy the area. Northern and arctic/alpine species (spring gentian, alpine bistort), grow together with southern continental (hoary rockrose). As the AONB includes the only English locality for some of this plant assemblage, as well as the most southern and northern locality for other plants, it is of great botanical importance.

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

Economic use

The area's metamorphic rocks have generally attracted little economic interest. The low grade metamorphic slates within the Teesdale Inlier were formely worked for the making of slate pencils, known locally as 'widdies', at the small quarry at Pencil Mill, on the banks of the Tees near Cronkley. Little is known of the physical requirements which suited the rock to this purpose, though the comparatively soft, fine-grained nature of the slates found here, together with their pale streak, are likely to have been key factors.

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

Blocks of a variety of Lower Palaeozoic rock types are incorporated into a number of vernacular buildings, drystone walls etc. in the area along the foot of the North Pennine escarpment.

Wider importance

The contact metamorphic rocks associated with the Whin Sill include some of the best examples of such contact altered sedimentary rocks in England. Despite the voluminous literature resulting from research on the Whin sill rocks themselves, the associated contact metamorphic rocks have hitherto attracted surprisingly little research interest. However, in recent years the discovery of suites of unusual metamorphic rocks, associated with the roof of the Sill in upper Teesdale, has prompted new research interest of relevance not just to the Whin Sill, but to the origins of similar metamorphic rocks in comparable environments far beyond the AONB. In addition to its importance as a fine example of a contact-altered limestone, the 'sugar limestone' of Teesdale hosts an internationally renowned flora.

Conservation issues

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

Currently protected sites of Metamorphic rocks within the AONB

SSSIs

The following sites lie within the Upper Teesdale-Moorhouse National Nature Reserve and SSSI:

Cronkley Pencil Mill, Upper Teesdale	NY848 296
Low Force and Wynch Bridge, Teesdale	NY905 279
Falcon Clints, Upper Teesdale	NY820 281
Cow Green Reservoir, Upper Teesdale	NY815 294
High Force, Upper Teesdale	NY880 283

RIGS

Metamorphic rocks are not present within any of the RIGS sites designated within the Cumbrian portion of the AONB.

Durham County Geological Sites

The following Durham County Geological Sites include significant exposures of metamorphic rocks:

Pencil Mill	NY848 296
Widdybank Fell	NY820 290

Other representative sites in the area

Greengates Quarry, Lunedale	NY933 234
Scoberry Bridge – Wynch Bridge, Teesdale	

Selected references

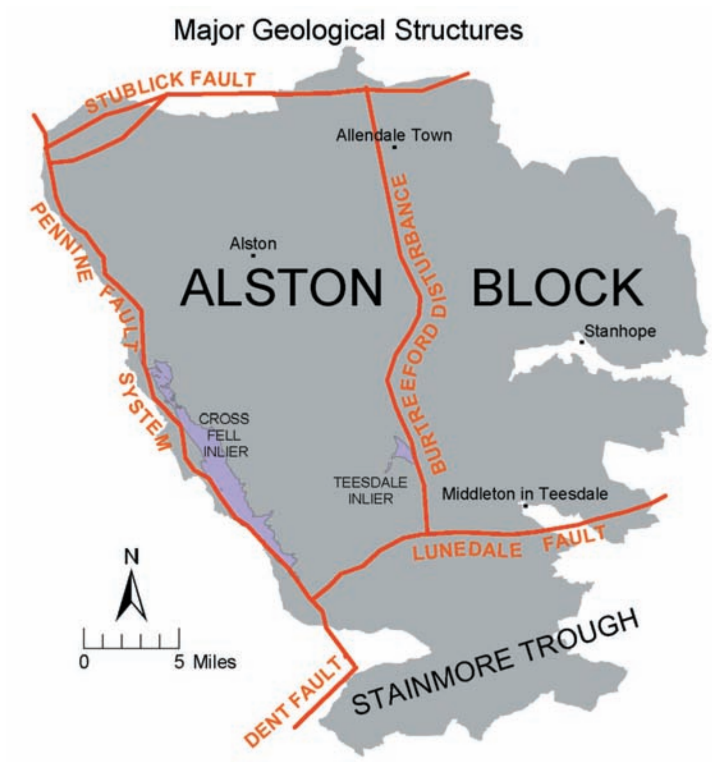
Dunham, 1990; Robinson, 1970; Stone et al, 2010.

Geological Structures

Geological structures are those features, including folds and faults, caused by the varying degrees of distortion suffered by rock units in response to earth processes. They may be viewed at a variety of scales ranging from huge structures affecting the entire region, to small folds or faults measurable in millimetres.

Geological structures in Great Britain

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



Geological structures in the AONB

The North Pennines includes much of the ***Alston Block*** and the northernmost portion of the ***Askrigg Block.*** These 'blocks' comprise fault-bounded platforms of Ordovician and Silurian rocks upon which the succession of Carboniferous rocks rests. They are termed 'blocks' because over millions of years of geological history they have remained as largely rigid masses, affected only by comparatively modest amounts of internal faulting and gentle tilting to the east.

The ***Alston Block*** is bounded by major fault systems on three sides, the ***Stublick Fault*** to the north, the ***Pennine Faults*** to the west, and the ***Lunedale-Butterknowle*** Fault to the south. Of these, the ***Pennine Fault System*** is the most prominent and complex. It consists essentially of two sub-parallel faults, the Inner and Outer Pennine Faults, between which are numerous small fault-bounded blocks of mainly Ordovician and Silurian rocks. The overall effect of this fault belt is to juxtapose Carboniferous rocks of the Alston Block and the younger, Permo-Triassic rocks of the Vale of Eden. The aggregate displacement, or throw, of this fault system amounts to many tens of metres.

The ***Askrigg Block*** is bounded on its western side by the ***Dent Fault System,*** which may be regarded as a southerly continuation of the complex Pennine Fault System.

Numerous faults cut the rocks of the AONB. These form a rectilinear, or conjugate, pattern and many of them are filled with minerals, giving the veins of the North Pennine Orefield. The rocks adjacent to many mineral veins exhibit evidence of folding and tilting.

The outcrops of Ordovician and Silurian rocks, surrounded by outcrops of Carboniferous and Permo-Triassic rocks along the line of the Pennine Fault System, are collectively termed the Cross Fell Inlier. A similar outcrop of Lower Palaeozoic rocks surrounded by Carboniferous rocks, in Teesdale, is known as the ***Teesdale Inlier***.

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

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

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

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

Impact on the landscape

Erosion of the comparatively flat-lying or gently dipping beds of Carboniferous rock gives rise to the almost flat, or gently inclined, hill-tops such as Cross Fell, which are such characteristic features of the North Pennine landscape.

The Pennine Fault System juxtaposes the comparatively resistant Carboniferous rocks of the North Pennines, with the relatively weaker Permo-Triassic rocks of the Vale of Eden. Differential erosion over millions of years has created the North Pennine escarpment, a prominent landscape feature of the AONB and one of the most conspicuous landscape features of northern England.

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

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

The Burtreeford Disturbance, though generally very poorly exposed, almost certainly determines much of the course of East Allendale.

"Normal fault in Great Limestone and overlying beds, Heights Quarry, Eastgate, Weardale" © B. Young, BGS, NERC.

Folded limestones adjoining the barites deposit, Closehouse Mine, Lunedale in 1984. © B. Young, BGS, NERC

Impact on biodiversity

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

Economic use

Almost all of the area's mineral veins occupy faults. An understanding of geological structure has lain at the heart of successful mining and prospecting. This understanding pre-dates the emergence of geology as an organised science. The earliest miners undoubtedly understood and applied many of the concepts and principles of modern structural geology. Geological structures place constraints upon the mining and quarrying of some rocks and minerals. This is especially so in places where faults displace, and thus effectively limit, the extent of workable rock units.

Wider importance

The Pennine Fault System brings to the surface important outcrops of Lower Palaeozoic rocks which give important clues to the concealed or basement rocks of northern England.

The major faults, the Stublick, Pennine and Lunedale-Boutterknowle faults, and the Alston Block which they bound, are all known to have had a long and complex history through geological time. Movement along these faults has influenced the Carboniferous and later geological history of northern Britain.

The conjugate pattern of mineralised faults of the Alston Block comprise the veins of the North Pennine orefield.

Conservation issues

Major landscape features determined by the larger geological structures, for example the North Pennine escarpment, are extremely robust. Exposures of particular geological structures, for example folds and faults, are comparatively few. Examples may be seen in many working or abandoned quarries and interesting structural features are exposed locally in some abandoned underground mines. Those in working quarries are likely to be destroyed during quarrying. Others could be damaged or destroyed by inappropriate restoration of old workings, or by collapse of underground workings.

Recent tree planting at Darngill Bridge in the South Tyne Valley threatens to obscure one of the area's most impressive sections of steeply dipping Carboniferous rocks adjacent to the Great Sulphur Vein.

Currently protected sites of Geological Structures within the AONB

SSSIs

No geological structures are currently notified as SSSIs,. However, numerous geological structures occur within the extensive Moorhouse – Upper Teesdale National Nature Reserve, and other SSSIs.

RIGS

Punchbowl Bridge, North Stainmore faults

Durham County Geological Sites

No geological structures are currently notified as Durham County geological Sites. However, numerous geological structures occur within many of these sites notified for other features.

Other representative sites in the area

River Wear, Cowshill	NY852 405	Steeply dipping strata in Burtreeford Disturbance
Closehouse Mine, Lunedale adjacent to Lunedale Fault	NY850 227	Spectacular folds in Dinantian rocks
Slitt Wood, Middlehope Burn	NY906 393	folded sandstones adjacent to Slitt Vein
Darngill Bridge, Tynehead	NY775 371	Steeply dipping strata adjacent to Great Sulphur Vein
Smallcleugh Mine, Nenthead	NY787 429	Numerous folds and faults exposed in underground workings
Rookhope Head	NY877 450	Exposure of fault in Namurian shales
Forest Head Quarries, Hallbankgate	NY584 574	Folds in Great Limestone

Selected references;

Arthurton and Wadge, 1981; Bott and Johnson, 1970; Burgess and Holliday, 1979; Dunham, 1990; Dunham and Wilson, 1985; Mills and Hull, 1976; Stone et al, 2010; Trotter and Hollingworth, 1932.

Mineral Veins

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

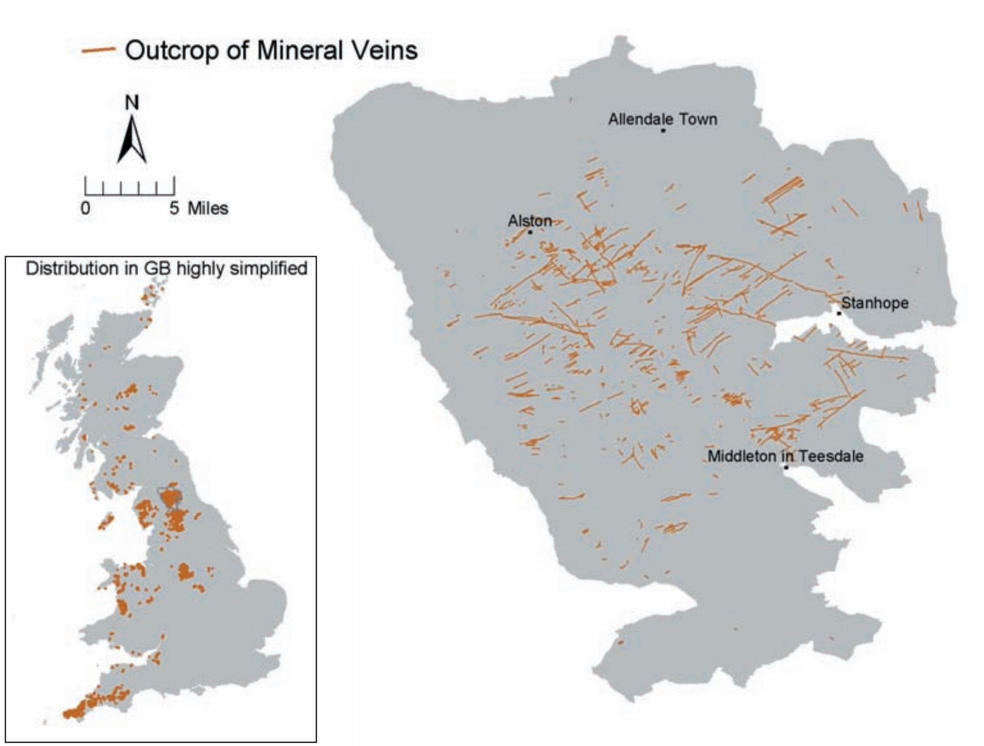
Veins may range from less than a millimetre up to several tens of metres in width. They generally comprise concentrations of minerals that may otherwise be extremely rare or widely scattered through the rocks. Some mineral veins are composed almost entirely of one introduced mineral, though more usually a variety of minerals are present, commonly forming crude bands approximately parallel to the vein walls. Minerals present may include one or more metal ores, generally accompanied by a variety of non-metallic minerals, known by miners as gangue, or as 'spar', minerals.

Associated with many mineral veins, particularly those in the North Pennines, are roughly horizontal bodies of mineral, known as 'flats', which may extend for several metres on one, or both, sides of a vein, usually within limestone wall-rocks. They represent bodies of limestone, wholly or partly replaced by the minerals found in the adjoining vein. Many of the features present within the original limestone, such as bedding and sometimes fossils, are replaced by minerals.

Cavities, or '***vugs***', in both veins and flats are typically lined with beautifully crystallised examples of the constituent minerals.

Mineral veins in Great Britain

Concentrations of mineral veins of many different types are found across Great Britain. Many of these have been important sources of metallic ores and other economically valuable minerals. Mineral veins and flats provide clear evidence of the circulation of large volumes of warm or hot mineral-rich waters deep beneath the Earth's surface. By studying their form, distribution, mineral content, chemical composition and many other characteristics, it is possible to deduce much about the sources of the chemical elements within the deposits, their temperature and age of formation and the geological environments in which they formed and evolved. Such investigations contribute to interpreting the deposits of an area and help to inform and guide exploration for similar deposits worldwide.



Mineral veins in the AONB

The veins, and associated 'flat' deposits, of the North Pennines AONB comprise the large group of deposits collectively known as the Northern Pennine Orefield. Lead and iron minerals were the principal ores worked, though smaller amounts of zinc and copper ores were raised locally, and some silver was recovered as a by-product during the smelting of many lead ores. The non-metallic minerals fluorspar, barytes and witherite were also mined, especially in more recent years.

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

"Witherite vein, Scraithole Vein, Scraithole Mine, Carr Shield"© T. F. Bridges.

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

Reaction the mineralising fluids and limestone wall rocks has locally created extensive 'flat' deposits. In most 'flats' within the North Pennines the main mass of the original limestone has been replaced by a compact aggregate of ankerite, siderite or quartz, though fluorite and baryte also replace the limestone locally. Within this altered rock occur bands or pockets of the ore minerals galena or sphalerite. Many 'flats' proved to be richer in ore minerals than the adjoining vein. Several 'flats in which the iron carbonate minerals ankerite and siderite were abundant were workable as iron ores, especially where later weathering had converted these carbonate minerals into oxidised, or 'limonitic' ores.

One of the best known features of the orefield is the striking zonal distribution of certain constituent minerals within the veins and 'flats'. The deposits within a central zone, which embraces much of Alston Moor, Weardale, Rookhope, parts of Teesdale, East Allendale and the Derwent Valley, are distinguished by containing an abundance of fluorite. Outside of this zone, fluorite is generally absent, its place being taken by the barium minerals barite, witherite, and locally, barytocalcite. This outer zone includes much of the Nent Valley, West Allendale, parts of Teesdale, Lunedale and the Pennine escarpment.

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

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

Impact on the landscape

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

The North Pennine Orefield is celebrated for the remains of the early form of opencast mining and prospecting known as 'hushing'. This involved the periodic sudden release of torrents of water from specially constructed dams high on a hillside, above a known or likely vein outcrop. The scouring effect of the water tore away at loose surface deposits, exposing the underlying

"Slitt Vein and worked – out ironstone flats, West Rigg, Westgate, Weardale" © B. Young, BGS, NERC.

rocks and any contained mineral deposits. Although it has commonly been supposed that these water torrents alone created the hushes, this is extremely unlikely, as the amounts of water available were almost invariably insufficient to dislodge and remove the large volumes of material necessary. It seems most probable that 'hushing' was employed as a convenient means of 'flushing' away rock loosened by previous manual excavation. Large elongated trenches, or hushes, are conspicuous features of the AONB landscape.

Most of the area's mineral deposits were worked from 'adit levels', driven into hillsides, or from shafts. Stone-arched adits are common landscape features. Many of the area's open adits are today protected by steel gates, though many have collapsed or 'run in'. They can be detected as distinctive shallow depressions in hillsides, often marked by a flow or seepage of mine water through the collapsed material. Shafts may be open, with or without protective fencing or walling, or may be 'run in' circular depressions, sometimes filled with water, or may be covered by distinctive protective stone 'bee hives'. Such unprotected shafts, adits or areas of collapsed ground may present significant safety hazards.

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

One of the most widespread landscape impacts of the area's mineral veins lies in the pattern of fields and settlements. The widespread development of the dual economy of farming and mining, during the 18th and 19th centuries resulted in the enclosure of large areas of otherwise uneconomic hillside and the development of scattered, isolated settlements. The area has a rich legacy of remains relating to the minerals industries. These remains comprise opencast workings, including hushes, spoil heaps, mine entrances, mine buildings and many miles of underground workings. All have considerable historical interest. Many are scheduled, or proposed for scheduling, as historical monuments.

Impact on biodiversity

An important feature of the area is the widespread occurrence of a number of specialised plant species and communities which exhibit a preference for higher than normal concentrations of heavy metals. These metallophyte and sub-metallophyte species include plants such as spring sandwort *(Minuartia verna)*, alpine pennycress *(Thlaspi caerulescens)*, scurvy grass *(Cochlearia pyrenaica)*, mountain pansy *(Viola lutea)*, thrift *(Armeria maritima)* and moonwort *(Botrychium lunaria)*. One or more of these species are commonly found on, or close to, the outcrops of mineral veins. They are especially common on areas of mine spoil or tailings. Concentrations of metal-rich soils, together with their associated rich metallophyte plant communities, adjoining many streams and rivers reflects the downstream erosion of such metal-rich sediments. Concentrations of metallophyte plants almost certainly served as important guides to the presence of ore deposits to early prospectors.

Several areas of mine spoil, which are contaminated either through elevated heavy metal concentrations or adverse soil pH values, remain virtually devoid of continuous vegetation cover, even after over a century. Severe heavy metal contamination is also a feature of soils close to a number of former lead and zinc smelting sites.

Miner-farmer landscape, upper Weardale. © Elizabeth Pickett/NPAP

"Spring Sandwort" © B. Young, BGS, NERC

Mine water discharges may carry high levels of contaminants which can affect land immediately surrounding the discharge. Where mine waters discharge into streams and rivers, these can have an adverse effect on the biodiversity of that watercourse. Notable examples of such heavy metal concentrations in surface streams include the River Nent and the Rookhope Burn. In the former, particularly high levels of zinc which may be related to mine and natural groundwaters passing through heavily mineralised ground, results in a severe restriction in the biodiversity of the river. In Rookhope Burn, significant contamination, including iron and zinc, has occured since the cessation of mine water pumping following the closure in 1990 of the Groverake-Frazer's Hush fluorspar mine near Rookhope.

Whereas the term 'contamination' is commonly used for such concentrations of heavy metals in soils and waters, it is important to appreciate that not all such concentrations are necessarily the result of the mining and processing of metal ores. The natural weathering and breakdown of locally abundant mineralisation may result in numerous entirely natural concentrations of very high levels of heavy metals. Entirely natural occurrences of heavy metal 'contamination' may be at least as widespread as anthropogenic concentrations.

Economic use

The mineral veins and flats have, over several centuries, provided the foundation for much of the area's economy. Available records indicate that over 4 million tonnes of lead ore, one third of a million tonnes of zinc ore, over 2 million tonnes of fluorspar, almost 1.5 million tonnes of barytes and several thousand tonnes of witherite and very large, but unrecorded, tonnages of iron ore have been mined from the hundreds of veins and associated flat deposits.

Discharge of brown iron-rich minewater entering Rookhope Burn near Ripsey Mine, 2007. © B. Young, BGS, NERC

Large scale mining for vein minerals ended in 1999 with the final closure of the combined Groverake-Frazer's Hush fluorspar mine. At the time of editing (January 2010), working for minerals is restricted to Rogerley Mine at Frosterley, where a small fluorite-rich 'flat' is being mined for several months each year as a source of fine mineral specimens by a small partnership of California-based mineral dealers.

In common with many of the world's disused mineral mines, the end of mining in the North Pennines owes more to the fluctuation in world metal prices than to the exhaustion of the deposits. The collapse in world lead prices precipitated the closure of all but a handful of lead mines towards the end of the 19th Century and by the mid 20th Century even this small number of survivors had succumbed. The large-scale working of fluorspar, which to a small extent helped to offset the effects of the collapse of lead mining, prospered during parts of the 20th Century. However, the availability of cheap fluorspar from countries such as China, brought about the demise of fluorspar mining in the North Pennines during the 1990s. Whereas there are good grounds for supposing that significant reserves of lead and zinc ores and fluorspar may be present within the area, any serious interest in commercial exploration depends on a significant rise in world mineral prices and would have to be undertaken in line with national planning regulations for AONBs.

Wider importance

The area's mineral veins and flats exhibit a number of features which give them national and international importance. Similar orefields within the USA have given the name 'Mississippi Valley Type (MVT)' to these orefields worldwide. The Northern Pennine orefield is one of the worlds finest, and best known, examples of such an MVT orefield.

Whereas many aspects of the mineralisation have clear parallels with broadly similar orefields elsewhere, the North Pennines exhibits several distinctive or unique features. Of particular importance is the very clear zonal arrangement of minerals within the orefield and the significance of this in understanding the origins and evolution of the mineralisation, particularly the relationship with the concealed Weardale Granite. Concepts and theories developed here continue to be of vital importance in understanding similar orefields across the world.

The orefield is remarkable for the abundance of carbonates of iron, magnesium, managenese and calcium as the minerals dolomite, siderite and ankerite, which occur widely in veins and flats. These mineral assemblages still offer considerable research potential which is likely to shed important light on the origin of these and similar deposits. The widespread abundance of barium carbonate minerals in the area's mineral deposits is a feature which makes the North Pennines unique in the world (see ***Minerals and Mineralogy***).

The veins and associated deposits of the North Pennines have long been a source of beautifully crystallised examples of many of the constituent minerals. In addition, observations, practical experience, interpretations and theories which flowed from the activities of generations of miners have been crucial to the understanding of not only the North Pennine deposits, but of similar deposits across the world.

"Lady's Rake Mine, an extremely important mineralogical site with mining history interest." © B. Young, BGS, NERC.

Conservation issues

Although many important surface exposures of mineral veins and flats remain, many of the finest exposures lie underground in long-abandoned workings. Although many of these remain accessible with appropriate care, such workings must always be regarded as potentially unstable.The continued accessibility of such exposures can thus not be guaranteed.

In addition to surface and underground exposures of mineral veins and flats, material within the numerous spoil heaps at many of the mines across the North Pennines provides the only remaining evidence of the deposits once worked. They thus constitute important, in some instances unique, resources of geological and mineralogical material and information. Removal of spoil heaps, either as sources of low-grade aggregate, or as part of programmes of land reclamation, may pose serious threats to these resources.

Uncontrolled collecting of mineral specimens at the surface and underground, both by amateur and commercial collectors, poses a significant threat to the integrity, research and heritage value of many sites across the AONB.

Currently protected sites of Mineral Veins within the AONB

SSSIs

SSSI NAME	GCR NAME	GRID REF
Appleby Fells	Scordale Mine	NY762 226
Blagill Mine	Blagill Mine	NY741 473
Closehouse Mine	Closehouse Mine	NY850 227
Foster's Hush	Foster's Hush	NY859 204
Moorhouse & Cross Fell	Sir John's Mine	NY762 378
Moorhouse & Cross Fell	Windy Brow Mine	NY770 381
Old Moss Lead Vein	Killhope Head	NY820 433
River South Tyne & Tynebottom Mine	Tynebottom Mine	NY740 418
Smallcleugh Mine	Smallcleugh Mine	NY787 431
Upper Teesdale	Lady's Rake Mine & Trial Shaft	NY803 344
Upper Teesdale	Pikelaw Mines	NY902 314
Upper Teesdale	Willyhole Mine	NY805 336
West Rigg Open Cutting	West Rigg Open Cutting	NY911 391

RIGS

Haggs Bank, Nentsberry, Alston	NY767 452
Howhill Quarry, Alston	NY730 433
Nenthead, Alston Moor	NY785 432
Masons Holes, Scordale, Warcop	NY758 224

Durham County Geological Sites

Boltsburn Mine and Rookhope Borehole	NY937 428
Closehouse Mine	NY850 227
Coldberry Gutter	NY940 292
Cow Green Mine	NY810 310
Dirt Pit Mine	NY891 291
Greenhurth Mine	NY779 328
Greenlaws Mine	NY889 369
Grove Rake Mine and Opencast	NY895 441
Hunters Vein	NY859 205

Other representative sites in the area

Browngill Vein, River South Tyne, Garrigill	NY744 418
Nenthead	NY788 430
Nentsberry Haggs Mine, Nenthead	NY7660 4502
Rampgill Mine, Nenthead	NY7818 4350
St Peter's Mine, Spartylea	NY8515 4876
Rogerley Mine, Frosterley	NZ0104 3814
Queensberry Ironstone Workings, Cowshill	NY857 410
Sedling Mine, Cowshill	NY859 409 – NY868 407
Frazer's Hushes, Rookhope	NY885 445
Boltsburn Mine, Rookhope	NY9368 4279
Shildon Mines, Blanchland	NY959 510
Farnberry and Holyfield Mines, Alston	NY731 448
Cornriggs Mine, Alston Moor	NY7178 3724
Noonstones Hill, Alston Moor	NY742 382 – NY750 380
Great Sulphur Vein, Crossgill	NY7396 3830
Sir John's Mine, Tynehead	NY7616 3782
Smittergill Head Mine, Alston Moor	NY6739 3896
Windy Brow Vein, Dorthgillfoot, Tynehead	NY7610 3806
Hard Rigg Edge, Melmerby Fell	NY658 390
Dun Fell Hush, Great Dun Fell	NY712 318 – NY720 319
Grasshill Mines and Highfield Hushes, Harwood Common, Upper Teesdale	NY819 355
Cowgreen Mines, Upper Teesdale	NY810 310
Wynch Bridge, Teesdale	NY905 275
Pike Law Mines, Newbiggin Common, Teesdale	NY902 313
Coldberry Gutter, Teesdale	NY924 290 – NY939 291
Greenlaws Mine, Daddry Shield	NY887367
Augill Beck, Brough	NY8219 1564
High Longrigg Mine, Kirkby Stephen	NY7985 0950

Selected references

Bevans*, et al, in press;* British Geological Survey, 1992; British Geological Survey, 1996; Dunham, 1990; Dunham and Wilson, 1985; Dunham et al , 2001; Forbes, Young, Crossley and Hehir, 2003; Stone et al , 2010; Symes and Young, 2008; Young, 1997, 2003

Quaternary Deposits

These varied deposits, and associated features, were formed during the Quaternary Period of Earth history between about 2.5 million years ago and the present day. The Quaternary Period is divided into two epochs: the Pleistocene which dates from 2.5 million years ago till 10,000 years ago and the Holocene which continues to the present day.

Quaternary deposits in Great Britain

At the start of the Quaternary, commonly called the 'Ice Age', an episode of global cooling resulted in the growth of ice sheets over much of Great Britain and Northern Europe. During the Quaternary, the climate oscillated between colder (glacial) and warmer (interglacial) stages. Approximately 14 stages of alternating glacial and interglacial conditions are believed to have occurred during the Quaternary in Great Britain. However, these are usually difficult to recognise in the sediments preserved today, owing to the destructive nature of the glaciers and ice sheets which removed the evidence of previous glacial episodes. The most recent (Devensian) glaciation terminated around 10,000 years ago. The extensive ice sheets, which in places were over 1km thick, resulted in erosion and modification of the existing landscape. The effects of persistent freeze-thaw action in ground which was often very deeply frozen, and the deposition of a variety of glacial sediments, further modified the pre-existing landscape.

Information derived from interpreting glacial landforms and the nature and morphology of glacial deposits, is essential to understanding the climatic conditions of the recent geological past. It may also provide valuable insights into likely future environmental changes related to possible global warming. Sediments deposited during interglacial periods, though preserved in comparatively few areas, record vital evidence about contemporary environments.

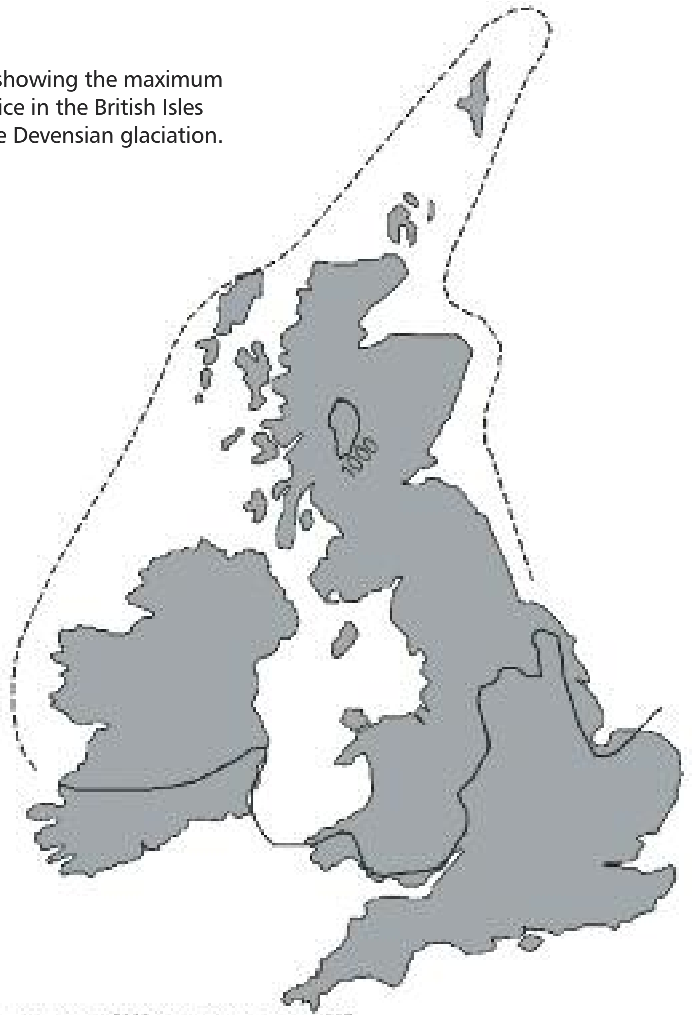
The deposits of the Holocene Period reflect erosion and deposition in a varied succession of environments during much milder climatic conditions. More recent, Holocene, fluvial deposits occur in almost all valleys or river courses. They are transitional, continuing to be affected by the river discharge controlling deposition or erosion of the sediment. These include a wide range of deposits including clays, silts, sands and gravels. Landslips occur in many areas and are not necessarily limited to steep slopes or hillsides. During the Holocene, peat deposits developed both in local topographic lows in the de-glaciated landscape and as extensive expanses of blanket bog over areas of high ground.

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

Quaternary deposits in the AONB

Quaternary deposits are widespread. They conceal the bedrock in many of the valleys and over substantial areas of hill country. In the North Pennines, as in much of Great Britain, the surviving deposits date mainly from the Devensian glaciation, with only very limited and uncertain evidence of earlier glacial and interglacial stages.

Diagram showing the maximum extent of ice in the British Isles during the Devensian glaciation.



Source: Everest (2003) after Boulton et al. (1985)

Detailed mapping of Quaternary deposits in the AONB is incomplete and it is not possible to depict adequately their distribution on a map at this scale. Except for geological mapping undertaken within the past three to four decades, the extent of superficial deposits is significantly under-represented on Geological Survey maps, as older surveys paid most attention to delineating bedrock, or 'solid', geology. The published geological mapping for the country extending northwards towards the Tyne Valley from Alston and Allenheads, including the valleys of the East and West Allen, lacks any depiction of Quaternary deposits, except for some Holocene fluvial deposits. Similarly, the absence of any adequate depiction of the extensive spreads of blanket peat over much of the Moorhouse-Upper Teesdale National Nature Reserve, reflects the late 19th Century vintage of much of the geological mapping here.

A number of topographical features, and the deposits of which they are composed, formed during Quaternary times, are considered below under the heading of Landforms. These include ***drumlins, moraine, kames*** and ***eskers***.

Quaternary deposits wthin the AONB include:

Till (or boulder clay) usually consists of a heterogeneous mixture of grey silty clay, with rock fragments ranging in size from gravel and pebbles to boulders: lenses of silt sand and gravel may be present locally. Till cover is widespread, though discontinuous, up to 615m above sea level. In places, notably parts of Teesdale, Weardale and the Vale of Eden, boulder clay occurs as elongate mounds known as ***drumlins*** (see **Landforms**, below). Till may fill pre-glacial, or buried, valleys (see **Landforms**, below). On the lower slopes in valleys, cover is generally asymmetrical with deep and extensive cover on valley sides facing away from the direction of ice flow (known as the lee side). This distribution pattern reflects the erosive activity of ice on slopes facing up-glacier. A feature of the till over substantial areas of the AONB is the local origin of many of the boulders within the till. This has been interpreted as evidence of the most recent ice sheets having their sources within the North Pennines, probably within the Cross Fell area.

"Boulder clay in river bank, Haugh Hill, Harwood Beck, Teesdale" © B. Young, BGS, NERC.

"Large limestone erratic, Herdship Fell, Teesdale" © B. Young, BGS, NERC.

Moraine is a term which was originally used to define the ridges of rock debris found adjacent to Alpine glaciers. This definition has since been expanded to include the rock debris deposit as well as the landform and is described as ***morainic drift***. Several types of moraine, which reflect both the form and the process by which they formed, may be recognised. In the AONB, morainic landforms include lateral moraines and ***hummocky moraine*** (see **Landforms**, below). Striking examples of morainic drift occur at the foot of Cronkley Fell in Teesdale.

Erratics are boulders or larger blocks of rock, most commonly within till, that have been transported by glaciers and deposited far from their original source. They may therefore provide clear evidence of the direction of ice flow. Within the AONB erratics of a variety of distinctive Lake District rock types are found, especially to the west of the North Pennine escarpment; erratics from southern Scotland are found in the north, adjoining the Tyne valley and its tributaries. In common with other parts of northern England, the North Pennines includes several striking examples of very large erratics, in some instances over several tens of metres across. These large erratics, or rafts, include the huge slices of Great Limestone which today form the Bulman Hills on Alston Moor and the masses of Dinantian limestones found on Herdship Fell to the west of Petergill Sike near Cow Green Reservoir.

Sand and gravel deposits are found mainly in limited areas on the North Pennine Escarpment. These are bodies of sand and gravel, deposited mainly by braided streams of water discharging from the Devensian ice sheets as they melted. These deposits may take the form of ***kames*** or ***eskers*** (see **Landforms**, below).

Peat deposits include both extensive blanket bogs, generally in the uplands, and basin peats. These latter deposits occupy hollows or depressions in glacial drift or ice-eroded bedrock. Generally blanket peat is around 2 metres thick, whereas basin peat may be much thicker. The extensive mantle of peat on Alston Moor, around the headwaters of the rivers Tees and Tyne, and extending up to Cross Fell, comprises one of Europe's largest and most important areas of blanket bog. Internationally important research into a wide range of environmental aspects of peat bogs of this sort, including their biodiversity, conservation and management, is currently being undertaken by the North Pennines 'Peatscapes Project'.

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

Scree and blockfields form as a result of the accumulation of angular rock fragments created by alternate the 'freeze-thaw' process during periglacial conditions. Blockfields accumulate on approximately horizontal surfaces and gentle slopes. Movement of broken rock in soil during prolonged 'freeze-thaw' action may create areas of patterned ground, including stone polygons or, on more sloping ground, stone stripes. Where such broken blocks have been moved by gravity down steeper slopes, accumulations of scree are the result. Examples of these can be seen on parts of the highest North Pennine hills. Scree forming talus slopes and cones are well-developed on the North Pennine Escarpment, especially beneath the Whin Sill outcrop at High Cup Nick.

Holocene fluvial deposits include a variety of sediments, ranging from silts and clays to coarse sands and gravels, which form flat spreads adjoining streams and rivers. Such deposits may accumulate as flat sheets on river or stream flood plains. Fluvial deposits occur in close proximity to all current river channels and some abandoned channels. ***River terraces*** are accumulations of similar materials above the modern flood level. They represent accumulations of alluvial material deposited during earlier phases of river development. They record changes in the river conditions and may reflect climatic conditions during Holocene times.

Impact on the landscape

Processes which were active during the Quaternary period have exerted an important influence on the landscape. The most important of these processes undoubtedly date from the major glacial episodes, though it is important to appreciate that, in common with all landscapes, that of the North Pennines remains dynamic and is still evolving.

Over much of the area, extensive spreads of till give rise to rather smooth slopes. The prominent terrace features associated with the cyclical deposits of the Carboniferous limestones, sandstones

"Pre-glacial channel of the River Tees (in background) Cauldron Snout" © B.Young, BGS, NERC.

"Peat overlying boulder clay, Plenmeller Opencast Coal Site" © BGS, NERC

and shales, locally contrast dramatically with much more subdued rounded till-mantled slopes. The deposition of till, notably in the central areas of the North Pennines, has caused an asymmetrical appearance to valleys such as the Nent and East Allen, with one smooth side and the other well-featured with solid bedrock benches. The 'half egg' shaped hills, known as drumlins, are characteristic of till in parts of Weardale, Teesdale and the Eden Valley at the foot of the North Pennine escarpment.

Complex patterns of glacial drainage channels, in places associated with deposits formed during ice-melting, are prominent on the steep slopes of the North Pennine escarpment.

Extensive areas of peat-covered blanket bog comprise one of the most distinctive, and internationally significant, landscape features within the AONB.

Holocene fluvial deposits form flat ground adjoining rivers and streams.

Impact on biodiversity

Where Quaternary deposits mantle the solid rock the soils reflect the composition of the 'drift' rather than the bedrock. These deposits also influence infiltration of water and the movement of groundwater. Sand and gravel deposits commonly support very well-drained soils in contrast to the poorly drained soils commonly found on spreads of till.

Extensive spreads of comparatively impervious till may have encouraged the development of blanket peat. The North Pennines hosts a major proportion of Europe's total area of blanket bog. Important research into the biodiversity and management of such upland peat bogs is currently being undertaken as part of the North Pennines 'Peatscapes Project'.

River terraces and alluvial deposits support a characteristic flora. Shingles are well - drained and adjoining rivers these areas may be subject to rapid erosion and flooding. Some plant species and communities are dependent on this erosion to suppress competition resulting from choking by faster growing species.

In addition, some fluvial deposits in the AONB support rare metallophyte plant communities including Thlaspi alpestre and Minuartia verna. These are found on gravel bars such as 'The Islands, Alston shingles' SSSI, where the fine sediment contains high concentrations of heavy metals derived both from natural concentrations of mineralisation and from mineral processing waste.

Economic use

Some of the small areas of glacial sand and gravel deposits have been worked as a local source of sand and gravel, particulary near the foot of the North Pennine escarpment. In addition, erratics boulders and clearance stones, derived from glacial deposits, have been employed in drystone walls and vernacular architecture (see Built Environment below). Peat deposits have been worked as a fuel both for domestic use andl for lead smelting.

Wider importance

The Quaternary deposits of the AONB provide important insights into the varied Earth processes that shaped the area during episodes of glacial, interglacial and post-glacial conditions. The importance of some of the area's Quaternary deposits in contributing to understanding of comparable deposits elsewhere in Great Britain and beyond is recognised in the designation of a number of GCR sites.

Conservation issues

Because most of the Quaternary deposits within the area comprise unconsolidated, or comparatively easily eroded, materials, permanent exposures are uncommon. Sections through these materials, in stream banks or in quarry faces typically degrade rapidly or soon become vegetated and obscured. Permanent exposures are few and generally difficult or impossible to maintain.

One of the most widespread, and internationally most significant, of the area's Quaternary deposits is the extensive covering of hill peat that mantles many of the interfluves. This very recent geological deposit has much to contribute to the understanding of past and present environments which may offer valuable insights into future environmental management. In addition, the blanket bogs of the North Pennines comprise a major proportion of the European resource of this unusual habitat. Internationally important research into a wide range of aspects of peatland environments, biodiversity and management is currently being conducted through the North Pennines AONB 'Peatscapes Project'. An important facet of current peatland management is the programme of blocking of drainage ditches (grips) to assist in restoring conditions favourable for preservation and re-establishment of peat formation.

Currently protected sites of Quaternary Deposits within the AONB

SSSIs

SSSI NAME	GCR NAME	GRID REF
Moorhouse & Cross Fell	Valley bog	NY763 331
Upper Teesdale	Upper Teesdale-Red Sike Moss	NY819 290
Moorhouse & Cross Fell	Cross Fell	NY687 344

In addition, a number of SSSIs in Quaternary deposits are listed in the section on landforms (see **Landforms**, below).

RIGS

Bullman Hills - North Pennines Giant erratics

Other representative sites in the area

River Tees, Cauldron Snout NY814 286 – till filling pre-glacial river channel

Haugh Hill, Harwood Beck, Teesdale NY859 297 – till exposure in side of drumlin

Knock Pike, Knock NY685 289 - cross-bedded glaciofluvial sand and gravel

Coalcleugh Moor, West Allendale NY796 446 - Peat

Selected references

Arthurton, R.S. and Wadge, A.J. 1981; Boulton, G. S. et al. 1985; Burgess, I.C. and Holliday, D.W. 1979; Duff, P.Mcl.D., Smith, A.J. 1992; Everest, J D. 2003; Gregory, K.J. 1997; Huddart, D. and Glasser, N.F. 2002; Johnson, G.A.L.(Ed.) 1995; Johnson, G.A.L. 1970; Mills, D.A.C. and Hull, J.H. 1976; Mitchell, 2007; Pounder, E. 1989; Stone et al, 2010; Trotter, F. M. And Hollingworth, S.E. 1932;

Landforms

Landforms provide clear evidence of the physical processes of erosion and deposition which have shaped, and continue to shape, the land over geological time. Most landforms are the result of processes which operated within the Quaternary Period. The scientific study of landforms is ***Geomorphology***.

Interpretation of landforms and Quaternary sediments can provide evidence of environmental conditions and climatic oscillations in the recent geological past. This includes evidence for the spread of ice sheets in Great Britain known as the 'last glacial maximum'. Such information may provide valuable insights into likely future changes as part of studies of climate change.

"The Great Whin Sill at High Cup Nick above Dufton on the Pennine Way" © Countryside Agency.

Landforms within the AONB

A variety of landforms may be recognised within the AONB. They can be dividied into several categories based on the processes that formed them.

Glacial erosion is the removal of rock and superficial material due to the movement of ice. Although northern England is known to have been covered by ice during several glacial episodes during the Quaternary, the features seen in today's landscape are mainly the products of processes that operated during the most recent, Devensian, glaciation and subsequent times.

Distinctive landforms related to glacial erosion, recognisable in the North Pennines include:

Glaciated valleys are those whose form has been significantly modified by the erosive power of moving ice. Whereas glaciers do not normally create valleys, they are known to be capable of causing substantial changes to a valley's original form. These effects include the truncation of spurs and the creation of a characteristic 'u-shaped' profile. The dramatic valley headed by High Cup Nick provides a good example of a glaciated 'U-shaped' valley.

Buried valleys are the pre-glacial valleys of the modern rivers which are now choked by, and concealed beneath, substantial thicknesses of till and other glacial deposits. The area's most striking example of such a buried valley is clearly visible at Cauldron Snout, where the till-choked pre-glacial valley of the River Tees lies a few tens of metres west of the present river course. The pre-glacial valley of the River East Allen lies a short distance to the west of the present course of the modern River Allen.

Glacial drainage channels, also known as meltwater channels, are channels of variable scale, usually steep-sided and flat-floored, cut by large volumes of water during the melting of ice sheets and glaciers. They are commonly unrelated to the present drainage pattern. Many are today dry and devoid of any stream, though some may carry disproportionately small, 'misfit' streams. Within the AONB good examples may be seen on parts of the North Pennine escarpment, in Teesdale and at several places in the Alston area.

Asymmetric valley profiles are a common feature of many North Pennine valleys. The North Pennine landscape is characterised by the stepped appearance of many hillsides, resulting from differential erosion of alternately resistant and less resistant beds of limestone, sandstone and shale. However, erosion by the Quaternary ice sheets has profoundly affected the form of many valleys, creating markedly asymmetrical profiles. These reflect strong glacial erosion, or 'plucking', on one side of the valley, with deposition of substantial spreads of glacial debris, mainly till, on the opposite side. Such valleys thus exhibit a stepped profile on the scoured side, with a much smoother profile on the side covered by glacial debris. The Nent and East Allen valleys are good examples.

Glacial striae, or striations, are grooves or scratches formed on bed-rock surfaces caused by the scouring effect of stones or boulders in the base of a moving ice sheet or glacier. Such striations are commonly exposed beneath sheets of boulder clay or till. Fine examples were formerly exposed beneath till exposed in the eroding sides of a drumlin at Haugh Hill, Upper Teesdale.

Glacial deposition involves the deposition of a range of sediments, mainly debris transported by ice sheets and glaciers. The nature of these Quaternary deposits is discussed above (see **Quaternary deposits**). Characteristic landforms resulting from deposition of glacial materials within the AONB include:

Drumlins are ovoid mounds of glacial debris, mainly till, which were deposited beneath an ice sheet and smoothed into a streamlined shape by the passage of the over-riding ice. The term drumlin is derived from 'druim', a Gaelic term for a mound or rounded hill. Typical drumlins exhibit an extremely distinctive 'half egg' shape. They commonly occur in large groups. The term 'basket of eggs' topography is sometimes applied to areas of well-developed drumlins. Within the AONB fine examples of drumlins occur in Teesdale, Weardale and in the Vale of Eden. The latter area includes concentrations of drumlins which, immediately beyond the AONB, exhibit typical 'basket of eggs' form.

Crag and tail refers to features formed where a resistant mass of rock has withstood the passage of an ice sheet, thereby protecting an elongated ridge of less resistant rock or debris on its leeward side. Within the AONB several small knolls, or 'crags', of Whin Sill dolerite in Teesdale, east of Langdon Beck, are associated with elongated 'tails' of till.

Moraine is a term which was originally used to define the ridges of rock debris found adjacent to Alpine glaciers. This definition has since been expanded to include the rock debris deposit as well as the landform and is described as ***morainic drift***. Several types of moraine, which reflect both the form and the process by which they formed, may be recognised. In the AONB some landforms have been interpreted as ***lateral moraines***, formed as accumulations of debris at the margin of a valley glacier.

Hummocky moraine is also present. This results from the thinning of the ice, possibly during melting of the ice sheet, and results in a strongly undulating surface with steep slopes and deep depressions. Striking examples of morainic drift occur at the foot of Cronkley Fell in Teesdale.

Kames are steep-sided ridges or conical hills, usually composed of stratified sands and gravels, formed from a crevasse filling in an ice sheet, or as accumulations of such materials on the surface of an ice sheet. Good examples occur at Fieldhead, north of Melmerby.

Eskers are narrow, sinuous ridges, typically composed of stratified sands and gravels formed either at the margin of a melting glacier or ice sheet, or within drainage channel beneath the ice sheet. That at Busk, north of Melmerby, is a typical example.

Periglacial features are those formed in periglacial conditions. The term periglacial is usually applied to the climate, processes and features created by freeze-thaw action in areas bordering ice sheets.

There is evidence that during parts of the Quaternary a few of the very highest points in the North Pennines may have been free of ice and stood up as ice-free peaks, or ***nunataks***. These would have been subject to freezing temperatures and thawing cycles that progressively broke down the rock and caused heave of the ground surface. Examples of the features formed in this environment include:

Blockfields or Felsenmeer are accumulations of angular blocks of frost-shattered rock , usually adjoining rock exposures (see ***Quaternary deposits*** above).

"Stone Stripes, Knock Fell." © C. Vye, BGS, NERC.

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

Gelifluction terraces are small terraces, formed by downhill movement of soil and superficial materials as a result of either seasonal freezing and thawing, or permafrost conditions. They may be difficult to distinguish from similar ***solifluction terraces***. Examples may be seen near the summits of Cross Fell, Knock Fell and Great Dun Fell.

Solifluction terraces are small terraces found on hillsides, formed by from downhill movement of soil and superficial materials. They may be difficult to distinguish from ***gelifluction terraces***.

Holocene landforms have developed through processes of erosion and deposition operating since the melting of the last ice sheets.

Incised valleys and incised meanders are deep river valleys resulting from a lowering of sea level, or an increased volume of drainage during post-glacial times. The River Derwent Gorge at Silvertongue is a superb example of a deeply incised meander cut during post-glacial times.

Landslips are masses of rock or earth which have moved downhill as a result of the failure of those on the underlying materials. They may result from the physical properties of the failed materials, or the geological conditions of their occurrence. A great variety of landslip types are recognised, reflecting the nature of the slipped material and the processes which caused the slipping. Mason's Holes in Scordale is a fine example of a large landslip.

Floodplains are the part of the river valley that is periodically flooded and built up from sediment deposited by the river both during a flood and when the channel migrates laterally. Wide flood plains flank the lower courses of the main rivers of the AONB.

River Terraces are part of the river valley that stands above the level of the present floodplain. Terraces develop due to a fall in the sea level, uplift of the land or a change in climate.

Wider importance

Study of the morphology and constituent sediments of the various landforms within the AONB enables interpretation of the history of glacial and post-glacial environments and processes both in the context of the North Pennines and more widely within Great Britain and Europe.

A number of alluvial deposits, including river terraces, in the area have been extensively studied and are recognised as giving important insights into a variety of Holocene fluvial processes. Studies have correlated the influence of mining in the AONB on fluvial systems and allow dating of relevant river terrace deposits. The first British site at which valley floor erosion and major flood events were related to sharp variations in climate is found within the AONB at Thinhope Burn.

Conservation issues

Landforms within the AONB are generally robust features within the landscape. However, more delicate features such as the blockfields and patterned ground on Knock Fell, Dun Fell and Cross Fell have suffered erosion by walkers and have sustained further damage caused by construction and repair of footpaths.

The large landslip at Mason's Holes, Scordale. © B.Young, BGS, NERC

Currently protected sites of Landforms within the AONB

SSSIs

SSSI NAME	GCR NAME	GRID REF
Alston shingle banks	River S. Tyne at Alston Shingle banks	NY716 441
Moorhouse & Cross Fell	Black Burn	NY684 411
River Nent at Blagill	River Nent at Blagill	NY744 467
River S. Tyne and Tynebottom Mine	River S. Tyne at Garigill	NY739 421
River W. Allen at	River W. Allen at	NY780 540
Blackett Bridge	Blackett Bridge	
Moorhouse & Cross Fell	Cross Fell	NY687 344

In addition to the above, the following have been identified as potential GCR sites for fluvial Holocene features:

Lambley, River South Tyne	NY675 605
Thinhope Burn	NY645 535

RIGS

Bullman Hills	NY705 372
High Cup Nick	NY422 260
Croglin Waterfall	NY600 481
Knock Pike – Flagdaw	NY687 286

Durham County Geological Sites

Folly Bollihope and Snowhope Carrs	NY966 367 – NY945 355
House glacial drainage channels, Egglestone	NZ011 231 – NZ027 236
Holwick drumlins, Romaldkirk	NY984 227
Knott's Hole meltwater channel	NY995 263
Knotty Hills and Hoppyland kames	NZ084 319 – NZ102 321
Sharnberry meltwater channel	NY991 307
St John's Chapel drumlins	NY875 384 – NY879 384

Other representative sites in the area

Ayle Common, Alston	NY71 50	Ice-scoured slopes
East of Eggleston	NZ027 228	Drainage channel
Great and Little Heaplaw, Alston	NY685 487	Drainage channel
Whitfield Moor, West Allendale	NY772 528	Drainage channel
Nenthall, Nent Valley	NY769452	Asymmetric valley profile
West Allendale	NY772 528	Asymmetric valley profile
The Eden valley (viewed from parts of the Pennine Way and Cross Fell) - Drumlins Teesdale valley	NY853 288 and 860 297	Drumlins
North-east of Watch Hill	NY631 467 to 633 464	four 'whaleback' drumlins
Seven Hill, Sleightholme	NY970 106	Hummocky moraines
Fieldhead	NY581 480	Kames
Busk	NY610 425 to 611 418	Esker
Mason's Holes, Scordale	NY755220	Landslip
Sparty Lea in Allendale	NY847 485	Landslip
Ouston Fell	NY762 518	Landslip
Hillbeck Wall End	NY780 168	Landslip
River Allen between Cupola Bridge and Allenbanks	NY880591 – NY798634	Incised valley
River Derwent Gorge at Castleside	NZ055491	Incised meander
River Tees	NY 868 280	Floodplain
Whitewalls burn, Ninebanks	NY776 521	River Terraces

Selected references:

Arthurton and Wadge, 1981; Burgess and Holliday, 1979; Duff and Smith, 1992; Forbes, Young, Crossley and Hehir, 2003; Gregory, 1997; Huddart and Glasser, 2002; Mitchell, 2007; Pounder, 1989; Mills and Hull, 1976; Stone et al, 2010; Trotter and Hoillingworth, 1932; Waltham, Simms, Farrant and Goldie, 1997.

Karst Features

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

Karst features in Great Britain

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

Karst features are found in areas of rock which are readily soluble in ordinary rainwater. In Great Britain these are normally limestones. Excellent karst features are therefore to be found in areas of extensive limestone outcrops. Notable examples include the outcrops of Carboniferous limestones in North and South Wales, the Mendips, Derbyshire, South Cumbria and the Yorkshire Dales. Good karst features are developed on comparatively small outcrops of Cambrian limestones in North West Scotland and the Isle of Skye.

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

Karst features may also form in such soluble rocks as gypsum. Although gypsum karst is known in a number of places in Great Britain, including the Vale of Eden, none is present within the AONB.

Karst features in the AONB

Although limestones are important components of the succession of Carboniferous rocks within the AONB, they are mostly comparatively thin and separated from one another by substantial thicknesses of insoluble rocks such as shales and sandstones. Thick limestones are present locally only along parts of the North Pennine escarpment, particularly in the south of the area.

Karst features present within the AONB include ***sink holes*** or ***dolines, caves, natural bridges, limestone pavement, tufa*** and ***stalagmitic deposits***.

The outcrops of many of the area's limestones are associated with lines of ***sink holes*** or dolines which, in areas with a moderate covering of superficial deposits, may provide valuable clues to the presence of limestone. Particularly good examples may be seen marking the top of the Great Limestone at numerous places in the Alston area, in West Allendale and in parts of Weardale and Teesdale. Springs, or lines of springs, occur close to the base of many limestone outcrops.

The few cave systems known in the North Pennines are relatively small and do not match the spectacular systems of the Yorkshire Dales. The area's best known caves include those at Harehope Quarry and Fairy Holes, in Weardale, Knock Fell Caverns on the North Pennine escarpment, the Teesdale (or Moking Hurth) Cave near Langdon Beck and Ayle Burn Cave near Alston. The Teesdale Cave is known to have yielded mammalian bones.

Knock Fell Caverns have been designated as a GCR site as the finest example in Britain of a joint-guided phreatic maze cave, with more than 4500m of passages within a single limestone in an area of less than 3ha.

The Fairy Holes Cave, also designated as a GCR site, is the finest and longest of the linear caves developed within the simple drainage pattern typical of the thin Yoredale limestones, which are characteristic of the North Pennines.

Areas of limestone pavement are very limited within the AONB, though good examples are present on the limestone outcrops of the North Pennine escarpment north of Brough and on the Great Limestone outcrop between Banks Gate and Palliard, east of North Stainmore. Areas of metamorphosed Melmerby Scar Limestone ('sugar limestone') occur on Widdybank Fell, Teesdale, where free of soil cover, locally exhibit rounded surfaces and widening of joints reminiscent of limestone pavement.

The AONB contains Britain's finest example of a natural limestone bridge, at God's Bridge near Bowes.

Small areas of ***tufa*** are forming adjacent to a lime-rich spring in Greenfoot Quarry, Stanhope. Small ***stalactite*** and ***stalagmite*** formations occur in many of the area's caves.

Limestone pavement, Stainmore. © Elizabeth Pickett/NPAP

Impact on the landscape

Karst features are locally conspicuous elements in the landscape, though they are of very limited extent. Most prominent are the areas of limestone pavement on the escarpment near Brough and near North Stainmore. Lines of sink holes, which are commonly associated with most limestone outcrops, are conspicuous locally. The comparatively small number of caves are significant, though concealed, landscape features.

Impact on biodiversity

Caves provide important specialised wildlife habitats. These include important bat roosts. The Fairy Holes Cave is said to support a unique fish population. Limestone pavement and limestone grasslands are important and scarce plant habitats. Lime-rich spring water locally has a strong influence on plant communities.

Economic use

Karst features appear to have been of little economic use locally, though it is possible that very small amounts of waterworn limestone from limestone pavements may have been recovered for ornamental garden use. Limestone pavement is today a nationally protected habitat / feature the extraction of which is no longer permitted.

Wider importance

Although karst features in the North Pennines are less prominent and generally much less well developed than in the nearby limestone country of South Cumbria and the Yorkshire Dales, the AONB hosts several extremely important features.

The importance of such sites as Knock Fell Caverns and Fairy Holes cave have been noted above.

God’s Bridge is regarded as Britain’s finest example of a natural limestone bridge.

God's Bridge, a natural limestone bridge over the River Greta. © Elizabeth Pickett/NPAP

Conservation issues

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

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

Limestone pavement is vulnerable to illegal extraction.

Currently protected sites of Karst Features within the AONB

SSSIs

SSSI NAME	GCR NAME	GRID REF
Fairy Holes Cave	Fairy Holes Cave	NY936 356
Moorhouse & Cross Fell	Knock Fell Caverns	NY720 307
God’s Bridge	God’s Bridge	NY957 126

In addition, the areas of limestone pavement known as Helbeck Scars, near Brough, is a proposed GCR site and may be scheduled as a SSSI.

RIGS and Durham County Geological Sites

There are currently no karst features designated as RIGS or Durham County Geological Sites in the AONB.

Other representative sites in the area

Bollihope Burn NY988 353 - Sink holes or dolines

Carrshield NY803 475 - Sink holes or dolines

Clarghyll, Alston NY725 490 - Sink holes or dolines

Ayle Burn Cavern, Alston NY728 497 - Cave

Palliard to Banks Gate, Stainmore NY864 135 – NY845 149 - Limestone Pavement

Helbeck Scars, Brough NY765 196 – NY795 160 - Limestone Pavement

Widdybank Fell, Upper Teesdale NY820 300 - Limestone Pavement

Selected references

Johnson and Dunham, 1963; Trotter and Hollingworth, 1932; Waltham, Simms, Farrant and Goldie, 1997

Fossils And Palaeontology

Fossils are the preserved remains of animals and plants. Commonly only the hard skeletal parts or shell of an animal, or the most durable portions of a plant, are preserved as fossils, although exceptionally the original soft tissue may be replaced. The imprints in soft sediment of soft-bodied animals such as jelly-fish and worms may be preserved. The trails, tracks, burrows and feeding traces of a variety of animals are commonly preserved as ***trace fossils***, as are the burrows and casts of worms.

Palaeontology is the study of ancient life. It is an essential tool in geology for the purposes of correlation, strata identification and establishment of sequences.

Palaeoecology, the study of the associations of coexisting fossil species, enables interpretation of ancient environments. Palaeoecology offers one of many links between geo- and bio-diversity. It has been estimated that the vast majority of biological species recognised by science are extinct.

Fossils in the AONB

Many of the principal fossil groups occur within the sedimentary rocks of the AONB, including trilobites, brachiopods, graptolites, crinoids, corals, ammonoids, gastropods, bivalves and plants. Detailed lists of the fossils recorded from the AONB are quoted in many of the literature references cited in the bibliography.

Internationally important assemblages of invertebrate fossils have been recovered from the Ordovician and Silurian rocks of the Cross Fell Inlier.

The area's Carboniferous rocks contain a wealth of fossils of both animals and plants. All offer important clues to the environments in which these rocks were deposited. Of particular note are the ***Chaetetes*** and ***Frosterley*** bands in the Great Limestone. These are notable for the abundance of especially well-preserved fossils of sponges in the former, and solitary corals in the latter see **Carboniferous** rocks, above, and **Frosterley Marble**, below).

The well-known fossilised cast of a large Carboniferous tree stump, complete with its root system, recovered from a quarry near Edmundbyers and now preserved in Stanhope Churchyard, is an especially fine example of such a large plant fossil.

The Quarterburn Marine Band, exposed in Quarter Burn near Egglestone, is a bed rich in marine invertebrate fossils, which marks the base of the Coal Measures in north-east England (see **Carboniferous rocks**, above).

Many of the Carboniferous sandstones contain striking examples of trace fossils, especially those of worm or mollusc trails. A bed, especially rich in such trace fossils, is exposed near Coalcleugh. A spectacular example of such a trail, present in a block of sandstone found near the Scordale mines, has been mis-identified as an early stone carving.

"Fossilised stump of a Namurian tree, preserved in Stanhope Churchyard" © B. Young, BGS, NERC.

Wider importance Some of the fossils from the area are of national or international significance. They are particularly important in the identification and correlation of the Ordovician and Silurian rocks of the Cross Fell Inlier. Pus Gill, the historical type section for the Pusgillian Stage of the Ordovician, is the type locality for several fossil species, including the brachiopod *Trematis corona* Davidson, and several species of trilobite including the trinucleid *Tretaspis duftonenesis* Dean. It is of key importance in the correlation of the Dufton Shale Formation and for international correlation of the standard British chronostratigraphical units at the Caradoc-Ashgill boundary.

The road cutting in the Ordovician Dufton Shale Formation at Melmerby is the type locality for an ostracod and several trilobite species. Swindale Beck is the type locality for six trilobite species.

Beds rich in the fossil alga *Girvanella*, within the Dinantian limestones have considerable importance for regional correlation. Similarly, the beds rich in sponge and coral fossils, the so-called *Chaetetes* and Frosterley bands within the Great Limestone are also of great significance.

The fossilised tree stump now in Stanhope Churchyard is an especially fine example of a Carboniferous tree.

Trace fossils found at Scordale, probably formed small molluscs or worms around 320 million years ago. © Brian Young

The Quarterburn Marine Band, taken as the base of the Coal Measures in north-east England, is exposed in Quarter Burn, near Eggleston.

Conservation issues

The impact of the collecting of fossils on the area's geodiversity is not known. However, as a European Geopark, the collecting of fossils within the AONB is strongly discouraged, except at supervised sites and for specific research projects. Inadvertent damage to key sections may result from inappropriate or careless use of these sites by educational or other groups.

The progressive deterioration of abandoned quarry faces, together with the risks of quarries being filled or landscaped may pose a threat to certain important fossil localities.

Careful curation of fossils collected from the AONB within museums, both local and national, is important in safeguarding this important aspect of the AONB's Earth science heritage.

Selected references

Arthurton and Wadge, 1981; Burgess and Holliday, 1979; Challinor, 1971; English Nature, 2000; Mills and Hull, 1976; Stone et al, 2010; Trotter and Hollingworth, 1932.

Minerals & Mineralogy

The precise definition of a mineral is *"A substance having a definite chemical composition and atomic structure and formed by the inorganic processes of nature"*. Individual minerals are generally referred to as species. The study of minerals is called Mineralogy. Rocks are composed of different minerals in varying proportions. Minerals may therefore be viewed as the essential components of rocks.

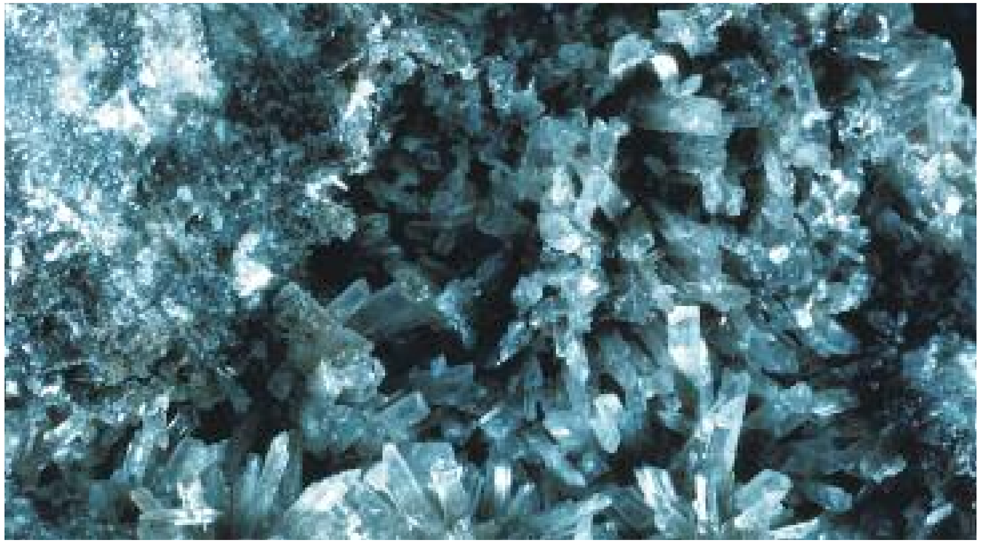
Outside the science of mineralogy, the term mineral is widely used to describe any natural product won from the earth. Thus, although sandstone, coal, oil, iron ore, and sand and gravel, are all commonly referred to as mineral products, they do not fulfil the strict definition of a mineral. This document is concerned with mineral species *sensu stricto*, as defined above.

Minerals in the AONB

Approximately 130 valid mineral species are reliably reported in the scientific literature from the North Pennines. Whereas many of these are found within the mineral veins and flats, others are known mainly, or solely, as components of rocks within the area.

The North Pennines includes the type localities for four mineral species: witherite; barytocalcite; alstonite and brianyoungite.

The mineral deposits of the North Pennines have long been a source of beautifully crystallised examples of several of their constituent minerals. Perhaps best known of these is fluorite, spectacular brightly coloured examples of which have been recovered from many mines, most



"Barytocalcite crystals, Clargill Mine, Alston" © BGS, NERC.

notably in Weardale, Alston Moor, East Allendale, and parts of the North Pennine escarpment. The area has yielded some of the finest known examples of this species. Striking specimens are to be found in countless museum collections and many are described and figured in numerous mineralogical publications.

The widespread abundance of barium carbonate minerals in the area's mineral deposits is a feature which makes the North Pennines unique in the world. Most abundant is the barium carbonate, witherite, which is a major constituent of many of the veins in the outer zones of the field. Elsewhere in the world this is an extremely uncommon mineral. Here in the North Pennines it is present in such abundance that it was for many years worked commercially as a raw material for the chemical industry. Also present, locally in some abundance and in places closely associated with witherite, are the even rarer double carbonates of barium and calcium, barytocalcite and alstonite. Both are extremely rare outside of the North Pennines. The reasons for this remarkable concentration of these minerals has yet to be determined. Superb specimens of these minerals from the North Pennines figure conspicuously in the world's mineralogical museums and collections.

Wider importance

The North Pennines has long been an internationally famous source of fine examples of numerous mineral species. Of particular significance are the magnificent specimens of fluorite, witherite, barytocalcite and alsonite. The area hosts the world type localities for the latter three species of barium carbonate minerals as well as the comparatively recently recognised zinc sulphate carbonate hydrate species brianyoungite.

"Fluorite crystals, Boltsburn Mine, Rookhope." *© Natural History Museum.*

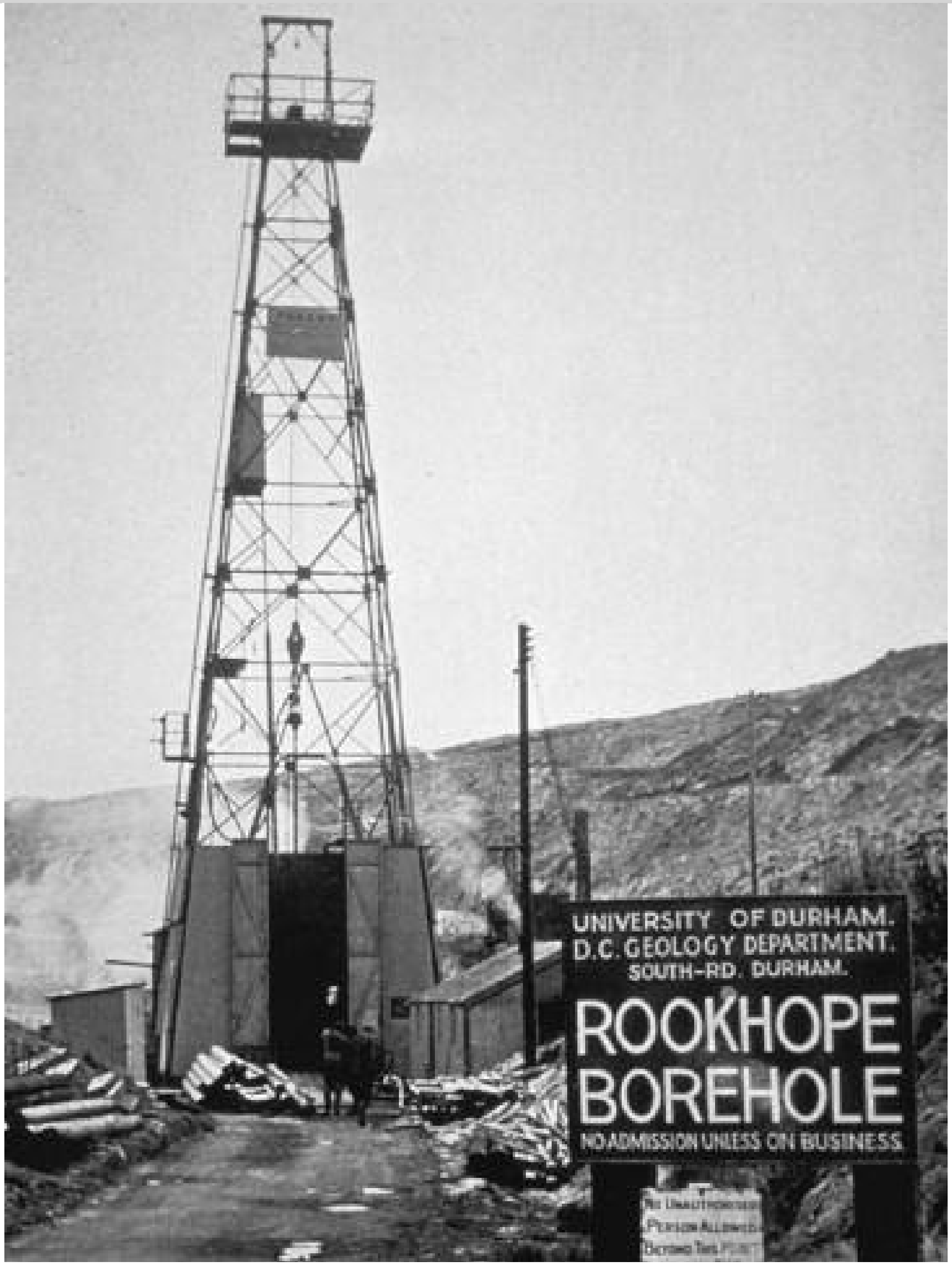
Conservation issues

Fine examples of several species, notably fluorite and the barium carbonate minerals, have long attracted collectors and good examples are increasingly scarce, even at localities formerly well known for them.

The collecting of minerals is an essential part of mineralogical science and has contributed, and continues to contribute, much to the understanding of mineralogy. However, uncontrolled collecting has, over the years, resulted in damage to several important mineral localities within the AONB. If such collecting is to be allowed to continue, suitable safeguards need to be devised to ensure that the benefits to be derived from responsible and informed collecting are not outweighed by the depletion and damage to the finite mineralogical resources. Collectors of minerals need to be encouraged, or perhaps required, to record and report the results of their collecting with the wider Earth science community and to deposit representative specimens with museums with major Earth science collections.

Seleceted references

Bevins *et al in press*; Dunham, 1990; Dunham and Wilson, 1985; English Nature, 2003; Fairbairn, 2003; Symes and Young, 2008; Young, 1997, 2003



The Rookhope Borehole, 1960-61 © University of Durham.

Geophysics

Geophysics is the study of the physical properties of geological materials and structures.

The modern science of geophysics embraces a very wide range of often extremely complex and sophisticated, techniques for measuring such parameters as gravity variations, magnetic properties, natural radiation, seismic properties etc. Study of these enables interpretation of the form and nature geological structures, often at considerable depths beneath the surface, and the processes which may have created them.

Geophysics in the AONB

Much of our understanding of the deep structure of the North Pennines is derived from geophysical investigations. Only those aspects of the area's geophysics which have most obvious impact upon geodiversity are considered here. Key references from the substantial technical literature on the geophysics of northern England, including the North Pennines, are listed in the bibliography.

During the 1950s, the North Pennines was a focus for early work on studies of gravity variations. Detailed gravity surveys revealed a pronounced pattern of negative ***Bouguer anomalies*** which provided strong supporting evidence for a concealed granite, first suggested to explain the nature and distribution of minerals within the North Pennine Orefield. Drilling of the Rookhope Borehole in 1960-61 confirmed the presence of the Weardale Granite.

The demonstration of the close genetic relationship between the distribution of minerals in the North Pennine veins with the form and extent of the concealed Weardale Granite, represents one of the area's most important contributions to the understanding of similar orefields worldwide.

Magnetic anomalies due to iron-rich basic igneous rocks, such as the dolerite of the Whin Sill, offer a useful means of inferring the presence of such rocks at depth or where concealed by superficial or other geological materials. Interpretations of magnetic anomalies associated with these rocks have contributed greatly to research into the concealed form and likely origin of the Whin Sill within the North Pennines. Such studies failed to support suggestions that the Whin Sill may have been emplaced via a feeder beneath Upper Teesdale, but gave evidence for the emplacement of this suite of intrusions through the major bounding faults of the Alston Block, such as the Lunedale and Stublick faults.

A number of ***seismic profiles***, mainly through areas immediately adjoining the AONB, give important evidence for the deep structure of the Alston Block.

Selected references

Bott,and Masson Smith, 1953; Bott and Johnson, 1970; Dunham, 1990; Dunham and Wilson, 1985; Stone et al, 2010.

Geochemistry

Geochemistry is the study of the chemistry of geological materials. It is an important tool in investigating the detailed composition of geological materials, as well as facilitating interpretations of the processes which have formed, and continue to influence, these materials. A range of analytical techniques in isotope geochemistry provides a diversity of methods for dating geological materials. Studies of regional geochemistry are important in mineral exploration and offer important means of investigating the distribution and dispersal of chemical elements in the environment.

Geochemistry in the AONB

Significant research on the geochemistry of minerals and mineral assemblages from the ore deposits of the North Pennine Orefield have greatly advanced understanding of their nature and origins, including the framing of important hypotheses on the origins of similar deposits worldwide. Particularly significant has been work on fluid inclusions and concentrations of rare earth elements.

The distribution of a large range of chemical elements in stream sediments and stream water across the AONB is depicted in two Geochemical atlases, published by the British Geological Survey. These provide a wealth of information on natural as well as anthropogenic concentrations of these elements, and can be used to interpret patterns of dispersion, including contamination, across the area.

Selected references:

British Geological Survey, 1992; British Geological Survey, 1996

Soils

An area's geological deposits provide the main source of inorganic ingredients for its soils. As the character of these soils is a major factor in determining the nature of the vegetation, there is a clear link between geodiversity and biodiversity. However, soil formation (pedogenesis) also depends upon other factors such as climate, weathering processes, vegetation, input of organic matter, groundwater movement, complex chemical reactions and even human intervention including agricultural practices. Therefore, whereas over substantial parts of the AONB the character and properties of soils may reflect the underlying geology, in other places the link may be much less clear.

It has not been possible within the scope of the production of this document to explore in detail the nature and distribution of the area's soils. More specialised information on soil character, properties and classification may be obtained from the publications of the Soil Survey of England and Wales.

Selected references

Jarvis, 1977; Jarvis, Bendelow, Bradley, Carroll, Furness and King, 1984; Soil Survey of England and Wales, 1983; Soil Survey of England and Wales, 1983

Mineral Extraction

The area has a very long and distinguished history as a producer of mineral products. Documentary records of mining for metals such as lead and iron exist from as far back as the 12th Century. It is possible that there was earlier mining for metals, though there is no identifiable evidence for this. It is, however, reasonable to suppose that mineral products have been raised from the area since the earliest days of human occupation.

Ores of copper, iron, lead, silver and zinc are known to have been worked here commercially:

Non-metalliferous minerals known to have been worked commercially are: barytes, barytocalcite, fluorspar, quartz and witherite

Rocks known to have been worked commercially are: coal, fireclay & brickclay, dolerite and other igneous rocks, limestone, peat, sand and gravel, sandstone (including ganister), moulding sand and slate.

Mineral extraction has had a profound effect upon almost every aspect of the modern landscape. The pattern of settlements, the road network, agricultural and land management practices can all be closely related to the former importance of mining, particularly for lead. Evidence of past or present mineral extraction can be seen in almost every part of the area. These mineral resources are clearly important elements in the area's geodiversity. Past and present workings offer a variety of opportunities for study.

The vital role played by mineral extraction in the geodiversity of the AONB is considered under the following headings: Abandoned quarries; Active quarries; Abandoned underground mines; Active underground mines; Spoil heaps

"Ancient Ironstone Workings, Cowshill, Weardale" © B. Young, BGS, NERC.

• **Abandoned quarries**

The area's long and distinguished history of mineral extraction has left a legacy of many hundreds of abandoned quarries, though there is no comprehensive register of their location and consequently it is not possible to depict them on a map. Certain geological units or formations have attracted particular economic interest. Numerous substantial quarries mark the outcrops of the Great Limestone, the Whin Sill, and several of the Namurian sandstones. The products of such quarries were mainly employed outside the AONB. Smaller pits, often worked only for very local use within the AONB are also common. In building dry-stone walls and farm buildings, it was common practice to obtain stone from as close as possible to the construction site. Thus, small pits are common alongside many lengths of wall, or close to farms or hamlets. Some of the area's mineral veins and related flat deposits were worked by quarrying. Peat is known to have been extracted on a substantial scale in the past, though none of these workings can be reliably identified today.

Abandoned quarries may be regarded as essential and distinguishing features of the present day landscape in many parts of the AONB. As disused quarries provide some of the most important, and several unique, sites at which certain rock units may be seen, they contribute greatly to the area's geodiversity.

In some instances their biodiversity interest may be significantly greater than their geodiversity interest. Abandoned quarry floors and faces offer a variety of substrates for specialised plant communities, including sites for lichens and other lower plants. They frequently offer excellent nest and roost sites for a variety of bird species, and may provide important bat roosts. Flooded quarry workings may offer important water bodies for aquatic life and a variety of bird species.

"Old Quarry in the Great Limestone, Bollihope Common" – Charlie Hedley © Countryside Agency.

Abandoned quarries are commonly seen as eyesores or convenient sites for waste disposal. Overgrowth of vegetation may spoil, or eventually totally obliterate, useful or important geological features. Reclamation schemes aimed at remediation of land affected by mineral extraction may destroy important or unique material.

• **Active quarries**

These comprise quarries at which mineral products are being produced, or at which planning permissions exist to allow such extraction.

Limestone is extracted at several quarries. The bulk of this is used as crushed rock aggregate or roadstone. Large blocks are occasionally recovered for use as armour-stone. A small amount of coral-rich limestone from the Frosterley Band within the Great Limestone at Broadwood Quarry in Weardale is recovered for use as ornamental stone.

Dolerite ('whinstone') from the Whin Sill is worked as an important source of roadstone from Force Garth Quarry in Teesdale. Some large blocks are recovered for use as armour-stone.

Sandstone is worked as a building, paving and walling stone from several quarries.

Active quarries provide fresh and constantly changing sections through the deposits being worked. They therefore provide some of the finest opportunities to further understanding and appreciation of the area's geodiversity. With appropriate planning for after-use quarries may also be developed as important future assets for biodiversity and recreation.

Active quarries offer opportunities to demonstrate the working techniques and the relevance of these industries within their local and regional communities. Significant opportunities exist at many active sites to plan after-uses which may be sympathetic to the conservation of important geological features. With appropriate imagination and foresight, many abandoned quarries can become considerable assets to the area's natural heritage.

• **Abandoned underground mines**

Accessible abandoned underground mines enable examination of numerous geological features associated with the mineral deposits formerly worked there, many of which may be rarely exposed clearly at the surface. Underground sites may provide unique opportunities to examine geological successions and structures in three dimensions and may offer the chance to study the mechanical and engineering properties of geological structures and materials. Many underground sites preserve geological features or materials in a comparatively unweathered condition, enabling comparison with surface exposures and therefore aiding understanding of a number of geological processes. Underground sites may also provide unique insights into the working practices adopted in mineral extraction. Abandoned underground mines therefore contribute greatly to the area's geodiversity.

"Surface plant, Groverake Mine (now disused), Rookhope" © B. Young, BGS, NERC.

The original stone-arched entrance to Cambokeels Mine, Weardale, driven in the mid-19th Century. © B. Young, BGS, NERC

Centuries of mining, mainly for lead ore and associated minerals, have left a vast legacy of many miles of undeground driveages and stopes. Whereas the majority of these have long been completely inaccessible, a substantial number remain in varying states of accessibility. Like abandoned quarries, it is quite impractical to depict all such sites on a map.

A number of the area's abandoned underground workings offer some of the clearest exposures available anywhere in Britain, or elsewhere, of several types of ore deposit. In particular, Smallcleugh, and nearby mines in the Nent Valley, provide extremely important sections through lead/zinc-rich flat deposits, including numerous features crucial to understanding their nature and origins. Parts of the underground workings of mines such as Blagill, Nentsberry Haggs and Brownley Hill expose barium carbonate mineralisation unique in the world. The latter mine includes the joint type location for the mineral alstonite, and the type locality for brianyoungite.

In addition to their vital contribution to the area's geodiversity, underground workings commonly support an important biodiversity. Many mine entrances and shafts are well-known and well-used bat roosts and some such workings provide specialised habitats for a variety of invertebrates, especially in their near surface parts. Timber, used within the mines may today host a range of fungal species.

All of the area's accessible abandoned underground workings exhibit significant features of industrial archaeological or historical interest, both above and below ground. Most of these workings are frequented by mine explorers, as well as mineral collectors. Clearly, access to such potentially unstable workings raises important considerations of safety and a range of conservation issues across several disciplines.

By their very nature, underground workings are especially vulnerable to deterioration. It is many years since most of the currently accessible workings were actively worked. Their stability and security is therefore almost entirely dependent upon the physical properties of the rocks through which the workings are excavated and the condition of any supporting structures placed by the original miners. In parts of many mines within the AONB, substantial parts of the workings lie within areas of competent rock which have stood with no support, or minimal support, in some cases for over two centuries. In other areas stone-arch supports, the traditional method employed in the North Pennines, continue to provide adequate support for many miles of workings. However, deterioration is inevitable and long-term stability and accessibility cannot be guaranteed.

Some rudimentary maintenance of wall-rock and roof support is undertaken by some groups of mine explorers anxious to maintain access to popular sections of workings. It is also common for mine explorers and mineral collectors to attempt to regain access to long-inaccessible areas of workings by excavating through blockages etc. Such work is generally of an *ad hoc* type and may not be based on expert civil engineering practices and may threaten the long-term stability of the workings. There is anecdotal evidence that illegal use of explosives has been used in collecting minerals from several mines. Mine exploration groups may offer opportunities to monitor the condition of workings and to recommend necessary remedial work.

Collecting of mineral specimens constitutes one of the most serious threats to both the accessibility and scientific value of many underground geological sites.

Two underground sites, Park Level Mine, Killhope, and Carr's Level Mine, Nenthead, are currently operated for public access and interpretation of mining and geological features.

• Active underground mines

Only one small underground mine is still active at the time of editing (January 2010). Rogerley Mine, within Rogerley Quarry in Weardale, is worked intermittently as a source of high quality fluorite specimens for the world mineral specimen trade.

Like active quarries, active underground mines provide constantly changing sections through the deposits being worked and thus have much to contribute to the understanding of the area's geodiversity. The fine exposures of mineralised ground, exposed in Rogerley Mine, have in recent years, figured in research into the origins of 'flat' mineralisation in the North Pennines. The mine workings offer very considerable opportunities for significant further research.

• Spoil heaps

Centuries of mineral extraction have left a varied legacy of mineral wastes in the form of spoil heaps from quarries, mines or mineral processing plants, including former metal smelting operations.

Because the great majority of the area's underground mines are no longer accessible for study, their associated spoil heaps may provide the only source of samples of the materials worked, or penetrated, in the mine workings. The technical literature includes many examples of descriptions and interpretations of important geological and mineralogical features based largely, or solely, on the evidence of materials contained in spoil heaps.

"Spoil Heaps, Coalcleugh Mine" © B. Young, BGS, NERC.

Exposure to weathering in spoil heaps may enhance the value of the materials present. For example, many fossils which may be extremely difficult to see in an unweathered exposure or quarry face, may be clearly exposed in weathered blocks in a spoil heap. A number of supergene mineral species may be forming within spoil heaps, particularly in waste materials from former smelting operations.

Spoil heaps are locally prominent in the area's landscape. Indeed, many of the spoil heaps associated with metalliferous mines may be viewed as essential features which help to characterise and define those landscapes. In some places spoil heaps may give the only clues to the presence of former workings.

Many spoil heaps offer a ready source of rubble suitable for earthworks or track-making. Reclamation and landscaping of areas of spoil deemed to be unsightly, may involve their concealment beneath spreads of top-soil, obliteration by tree planting or their complete removal. Natural erosion threatens a small number of scientifically significant spoil heaps. Uncontrolled collection of mineral specimens may seriously deplete their value. Spoil heaps may therefore be regarded as vulnerable elements in the landscape, susceptible to a variety of threats to their scientific value as important components of the area's geodiversity

Some spoil heaps provide an important habitat for a number of plant communities. These include limestone flora on the heaps adjoining some limestone quarries and metallophyte flora, including a variety of lower plant species, on numerous spoil heaps from metal mines and processing plants.

Several spoil heaps, particularly some associated with former metalliferous mines are included in the archaeological features scheduled at those sites. Scheduled Ancient Monument (SAM) designation normally precludes any form of disturbance, however minor.

Spoil heaps may offer important potential for sustainable educational and recreational collecting. Potential exists for mineral operators to make portions of spoil heaps accessible for educational or recreational use by groups or individuals. Such activities may include setting aside concentrations of waste material of particular geological interest. Excavation of a spoil heap offers important opportunities for recovery of significant material and associated recording of finds.

The Built Environment

The built environment includes houses, farms, churches, graveyards, schools and other public, industrial and commercial buildings, roads and highway structures. In the context of the North Pennines AONB it embraces vernacular architecture as well as countless miles of drystone walls and, underground, many miles of stone-arched mine tunnels and shafts. Where natural materials have been employed in their construction, all may legitimately be viewed as components of the area's geodiversity.

The built environment and geodiversity

The nature and appearance of stone-built structures in any area is directly related to the physical characteristics of the available rocks and the constraints those characteristics may impose on their potential use as constructional materials. Whereas it is generally appreciated that the character of local buildings is an important element in determining the character of a landscape, it may not be so readily appreciated that those buildings, and the material they contain, must be viewed as key components of the area's geodiversity. Built structures thus provide readily accessible opportunities to demonstrate the characteristics of a variety of local rock types.

Geological materials sourced from outside an area may be regarded as offering another useful dimension to the area's geodiversity. These materials may have been employed for specific purposes for which there are no suitable materials within the area. They may have been selected for aesthetic reasons. Recognition of the exotic nature of such stones, and understanding their original sources, is important in studies of the built environment and may be of practical application in planning repair or restoration work.

All of the geological materials employed in built structures can contribute greatly to an appreciation of the importance of the Earth's resources through understanding the properties and limitations of these materials. They are thus a potentially valuable educational resource.

Materials used in the built environment of the AONB

Despite the varied geology of the AONB, the range of rock types suitable for building is rather restricted. The main rock types employed are:

- **Sandstone**

The most commonly used stone in the North Pennines. Most of the sandstones used have been derived from the Carboniferous succession, though Permo-Triassic sandstones have been employed on the margins of the Vale of Eden, and locally elsewhere. Sandstones were mainly obtained either from quarries opened in the nearest available outcrop, or from clearance stones.

Almost any reasonably durable sandstone can be used for wall construction. Where stone was required for roofing, the choice of material, and source of supply, was rather more limited.

A feature of many North Pennine villages and farms is the use of sandstone slabs for roofing. The number of sandstones able to provide these was much more limited than those for walling stone. Although some roofing slab quarries can still be identified, the location of most of these is now lost. One small quarry, at Ladycross, just beyond the AONB boundary, continues to produce slabs suitable for roofing. This quarry is known to have been the source of roofing stone for many buildings within the AONB, notably those in Blanchland.

"Croglin. Use of local sandstone including St. Bees sandstone from the village quarry." Charlie Hedley © Countryside Agency

'Blanchland – use of locally worked sandstones as building and roofing stone' © B. Young, BGS, NERC

The builders of the many miles of drystone walls typically sought stone as close to the construction site as possible. A feature of many walls is the presence, at intervals along the course of the wall, of small pits from which stone was obtained, either from rock outcrops or from boulders within the superficial deposits.

A major use of building stone in the 18th and 19th centuries was in lining and supporting shafts and adit levels in the area's lead mines. The full scale of this commonly forgotten craft can only be appreciated underground in the many miles of adits which remain accessible, even after centuries of disuse and neglect. That so many of these stone-lined structures survive is a clear tribute both to the materials used and the highly skilled masons responsible for their construction. As the main mine shafts and adits were designed to serve for many years as the main access ways for the mines, considerable care was given to their design, construction and selection of the materials used. Waste rock from the mines was rarely, if ever suitable. Instead, specially quarried stone was taken underground for the purpose. Rather flaggy sandstone, capable of yielding parallel-sided slabs, was preferred. Quarries from which such stone was obtained can be identified close to many mines.

Sandstone setts were commonly used to pave roads in major settlements. Their use is today best seen in Alston, where Namurian sandstone from Flinty Fell Quarry at Nenthead provides an effective paving surface on the town centre's steep roads.

• Limestone

Except in the Kirkby Stephen area, where it is a comparatively common building stone, limestone has not generally been widely employed for building in much of the AONB. Limestone appears to have been commonly reserved for making of mortar.

The unique coral-rich limestone, known as ***'Frosterley Marble'*** (see **Frosterley Marble**, below), obtained from the Great Limestone, has been an important source of ornamental stone.

• Dolerite ('Whinstone')

Although an extremely durable rock, the dolerite of the Whin Sill has never been widely employed as a building stone, except in drystone walls on or close to its outcrops. This almost certainly reflects the hard, intractable nature of the stone, making it difficult to work.

Although little used for building, Whin Sill dolerite has long been employed as a good quality roadstone. Large abandoned quarries mark its outcrop in Teesdale. Force Garth Quarry, close to High Force, is today a major producer of crushed Whin Sill dolerite for road surfacing. Most of the roads in the area are surfaced with tarmac-coated dolerite.

• Clearance stones

Clearance stones from fields have locally been an abundant source of stone. Walls and buildings constructed from such stones can generally be recognised from the very varied nature of the stones and commonly the rather rounded outlines typical of boulders recovered from superficial deposits. These contrast with the angularity of freshly quarried blocks.

• Imported geological materials used in the built environment of the AONB

For most purposes there were few incentives to import stone into the AONB. The area has few buildings for which design specifications may have required the costly acquisition of such materials. However, some examples of imported stone are to be found.

Whereas sandstone slabs are perhaps the most characteristic roofing material in older buildings in the AONB, a significant number of slate roofs can be seen. Most common are Welsh slates, recognisable by their distinctive dark purplish grey colour. Fine examples can be seen at Hunstanworth. Lake District 'green slate' derived from the Borrowdale Volcanic Group, is employed locally, for example on the old school at Blanchland.

Building stones from outside the area are uncommon, though some good examples of Penrith Sandstone can be seen in a bank in Alston.

A variety of exotic stones, perhaps including some from overseas, may be seen employed in gravestones, and to a limited extent as ornamental stones churches. A conspicuous example is the use of polished Shap Granite pillars in St Augustine's Church, Alston.

Pillars of polished Shap Granite, St Augustine's Parish Church, Alston. © B. Young, BGS, NERC.

Impact on the landscape

Building design, and the materials used, have had a significant impact on local landscape character. The settlement pattern in the North Pennines is basically an agricultural one, overlain by, but not always submerged by, the industrial activities and mineral workers' settlements developed mainly over the last 250 years. The pattern of rural building existing today varies through the AONB from the scattered farmsteads of the Strathmore and Raby estates in Teesdale to the more dense lead mining and subsistence smallholdings of the Nent and Allen Valleys and Weardale.

The North Pennines has listed buildings ranging from Anglo-Saxon times to the Victorian era. The greatest number belong to the 18th and early 19th Centuries, which is a reflection of the high standard of architecture and the high survival rate of buildings of those times, partly because of their relatively recent construction. This is also a note-worthy period for the variety of buildings which are listed. These include great country houses like Horsley Hall, town houses like those in Alston and Middleton-in-Teesdale and village cottages like those at Wearhead, Melmerby or Allenheads. Earlier buildings are not so common, simply because time has taken its toll. In most instances it is only the more substantial and higher status ones which have survived, such as manor houses (eg Stanhope Hall), bastles (e.g. Monk, West Allendale) and churches (e.g. Blanchland).

The composition of drystone walls typically closely mirrors the local geology. In places the drystone walls give important clues to the underlying geology where this may not be clearly visible.

Impact on biodiversity

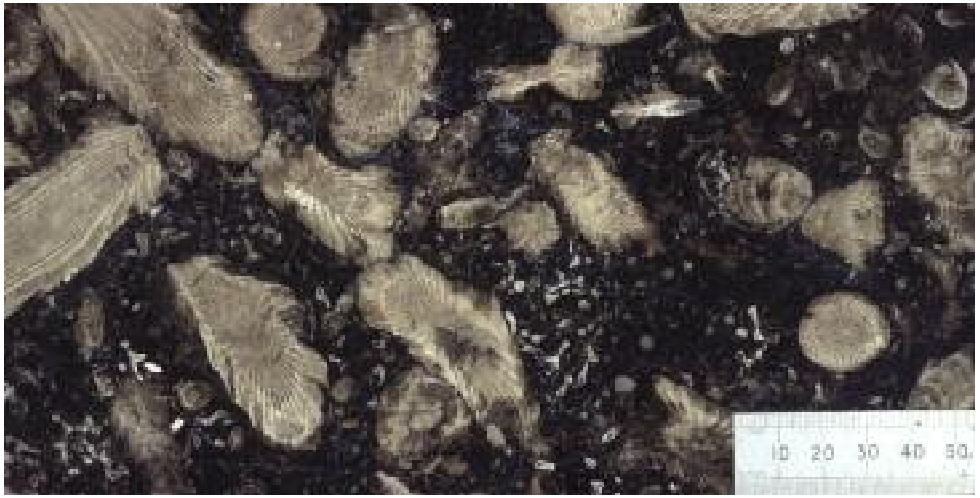
Rocks in walls and buildings provide important substrates for a variety of lower plants, including mosses and lichen and nest sites and shelter for several bird species and small mammals.

Selected references

Forbes, Young, Crossley and Hehir, 2003; Johnson and Dunham, 1982; North Pennines AONB Partnership, 2004

Frosterley Marble

Frosterley Marble is a name widely used for a distinctive bed, or 'post', of limestone up to about 1 metre thick, which occurs between 6 and 7.5 metres below the top of the Great Limestone, over a large part of Weardale and parts of Teesdale and the North Pennine escarpment (see ***Carboniferous rocks***, above). Sometimes referred to as the 'Frosterley Band', it is not a true marble, but is a dark grey, to almost black, rather bituminous limestone in which very well preserved fossils of the solitary coral *Dibunophyllum bipartitum* are extremely abundant. Other corals, brachiopod, bivalve and crinoid fragments are also present, but comparatively inconspicuous compared to the large solitary corals.



"Frosterly Marble, polished surface" © BGS, NERC

Frosterley Marble in the AONB

The Frosterley Marble is exposed in several of the numerous quarries in the Great Limestone, though is often rather inaccessible in high faces. The best exposures are in Weardale, though many are immediately outside the AONB.

The coral-rich Frosterley Marble, or bioherm, is an extremely important 'marker bed' within the Great Limestone. It contains a very rich, and very well preserved marine fauna and thus gives valuable insights into the palaeontology and palaeoecology of the Carboniferous Period in this part of northern England.

Harehope Quarry, the nearby bed of Harehope Burn and the Killhope Burn upstream from Killhope Lead Mining Museum, offer the best and most readily accessible natural exposures of the rock in the AONB. Very fine and extensive exposures remain in parts of the now disused Eastgate Quarry, though these are not publicly accessible.

Within the AONB, good worked examples of Frosterley Marble may be seen in churches at Eastgate and Alston. Beyond the designated boundary, excellent examples of the ornamental uses of the stone may be seen at:

- Frosterley Church (font)
- Stanhope Church (font, table-top tombs, coffin)
- Eastgate Church (font)
- Wolsingham Church (chancel floor)
- Auckland Palace Chapel
- Durham Cathedral (extensively used as pillars in Chapel of Nine Altars, Chancel, Rood Screen, Gallilee Chapel, flooring)

Impact on the landscape and biodiversity

As a single bed within the Great Limestone (see **Carboniferous rocks**, above), the Frosterley Marble itself has little individual impact upon the landscape or biodiversity of the AONB.

Economic use

Working of Frosterley Marble as an ornamental stone is known to extend back over several centuries. In addition to its use in making internal ornamental pillars in churches, it has been much used in making fonts, tombs and even wash-stand tops. Substantial amounts of the stone are employed as pillars and flooring slabs in parts of Durham Cathedral built during the 12th Century. Frosterley Marble fonts are known in several churches in Weardale. It is commonly supposed that much of the stone employed in Durham Cathedral originated from Harehope Quarry, at Frosterley, immediately outside the AONB, though other sources may also have been exploited.

As well as in buildings in and near the AONB, Frosterley Marble may be seen, employed as an ornamental stone in York Minster, Truro Cathedral, the Roman Catholic Cathedral in Norwich, and in Mumbai Cathedral, India.

For many years little Frosterley Marble was worked as an ornamental stone, except on a very limited scale for small ornaments. In recent years Frosterley Marble has, from time to time, been recovered for use as an ornamental stone, during quarrying of Great Limestone at Broadwood Quarry, Frosterley, immediately outside the AONB. The amounts worked are not known, but are likely to be small.

Wider importance

Solitary corals of the type found within the Frosterley Marble are common in many of the Carboniferous limestones of Great Britain. However, the great concentration of these corals and associated fauna in the Frosterley Marble, appear to be unique to this part of northern England. This highly distinctive rock is thus both an important part of the Carboniferous succession and an extremely important element within the geodiversity of the AONB.

Conservation issues

The finest natural exposures of Frosterley Marble within the AONB appear to be comparatively robust. However, as with all such natural exposures, they should be monitored for condition and vigilance maintained for future threats. The finest exposures of this unusual rock lie immediately outside the AONB.

Currently protected sites of Frosterley Marble within the AONB

SSSIs

The exposures in Killhope Burn form part of the Old Moss Vein SSSI, designated primarily for its mineralogical importance.

Selected references

AONB Partnership 2008, Dunham, 1990; Forbes et al, 2003; Johnson, 1958

"Font in Frosterly Church" © B. Young, BGS, NERC

Spar Boxes

These unusual objects, the making of which seems to have been unique to the north of England and Isle of Man, provide a very clear link between facets of the area's mineral resources and its social and economic history, and deserve to be considered here as part of the geodiversity of the AONB.

Spar boxes are cabinets lined with crystals of minerals found in the lead mines of the North Pennine dales. They vary in size from small cabinets of less than a metre across to larger ones of several metres.

Some spar boxes are comparatively simple and comprise a small cabinet lined with colourful crystals selected purely for their aesthetic effect. More elaborate spar boxes incorporated mirrors, models of mining or architectural features, and on occasions a number of lighting effects. Some spar boxes incorporated stuffed and mounted birds, in addition to minerals.

A number of 'spar models' or 'spar towers' are also known. These consist of assemblages of selected crystals mounted in the form of a tower or mound and commonly covered by a bell jar. The tradition of making spar boxes seems to have been concentrated in the lead mining areas of the North Pennines, the iron mining areas of west Cumbria and the Isle of Man. It is known that spar boxes were exhibited competitively at shows in the dales. There is no evidence of spar box making in other UK mining areas.

"Spar box with North Pennines minerals"
© Killhope Lead Mining Museum

Fluorite, in various colours is usually a major component of local spar boxes, accompanied by quartz, calcite and commonly by examples of ore minerals including galena.

An interesting feature of many North Pennine spar boxes is the inclusion within them of minerals clearly identifiable as being derived from the west Cumbrian iron ore field. These include striking examples of aragonite, calcite and on occasions haematite in a number of forms. It seems that some form of trade or exchange of specimens was routinely practiced by miners and spar box makers.

Spar boxes provide a superb opportunity to link the appreciation and understanding of earth science with an unusual rural craft tradition.

Spar boxes in the AONB

Spar boxes were once commonplace items of domestic decoration in many dales cottages. With the passage of many years since the demise of widespread lead mining, and the increasing interest and associated commercial value placed upon mineral specimens, spar boxes have attracted the attention of dealers and collectors. This has seen many examples leaving the area.

Killhope, the North of England Lead Mining Museum, holds a major collection of spar boxes. These include the famous Egglestone Spar Box, probably dating from around the end of the 19th Century and believed to be the largest ever made.

Wider importance

Although spar box making cannot be seen as a form of systematic collecting and curation of mineral specimens as scientific objects, it is an extremely important facet of the local mining tradition. Surviving spar boxes represent both an interesting resource of mineral specimens and an important legacy of a tradition almost unique to this mining field.

Many of the surviving spar boxes are known to have been assembled in the AONB, especially in Weardale, from locally mined minerals. In addition to their obvious cultural interest, spar boxes offer an extremely valuable, and rather novel, means of introducing the rich mineralogical heritage of the area to a wide audience.

Conservation issues

As it is known that the making of spar boxes figured prominently in the spare-time activities of many North Pennine miners, it is likely that large numbers were made during the peak years of mining in the 18th and 19th centuries. Within living memory, spar boxes were comparatively common objects in many dales households, though they are generally scarce here today. Many have been acquired by dealers and collectors, and no longer remain within the AONB. Some, perhaps many, may have been destroyed.

The collection held at Killhope is almost certainly the largest and most complete collection of these curious products of the area's mining legacy.

Selected references

Forbes, I. (undated); Symes and Young, 2008.

Geological Models

Geological models are three-dimensional representations, often in simplified form, which have been used to illustrate a variety of geological structures or features. It was common practice, until the advent of sophisticated computer graphics, to construct such models during mine planning and development to assist in visualising geological structures and their complex relationships.

These models, especially those which illustrate the structural and stratigraphical relationships of mine workings, provide important evidence for features which, though of great scientific significance, are no longer be accessible for study. As important aids to the understanding of such features they are essential elements in the area's geodiversity..

Geological models in the AONB

Two important groups of geological models exist locally.

Sopwith's models:

The 19th Century mine agent and influential pioneer of geological thinking within the North Pennines, Thomas Sopwith (1803-1879), produced a number of wooden models to illustrate key geological structures encountered during mining and mineral exploration. A skilled carpenter by training, Sopwith produced these models using beautifully carved inlaid and layered combinations of woods of different colours. His models became highly regarded and were sold widely beyond the North Pennines, though examples are rarely seen today.

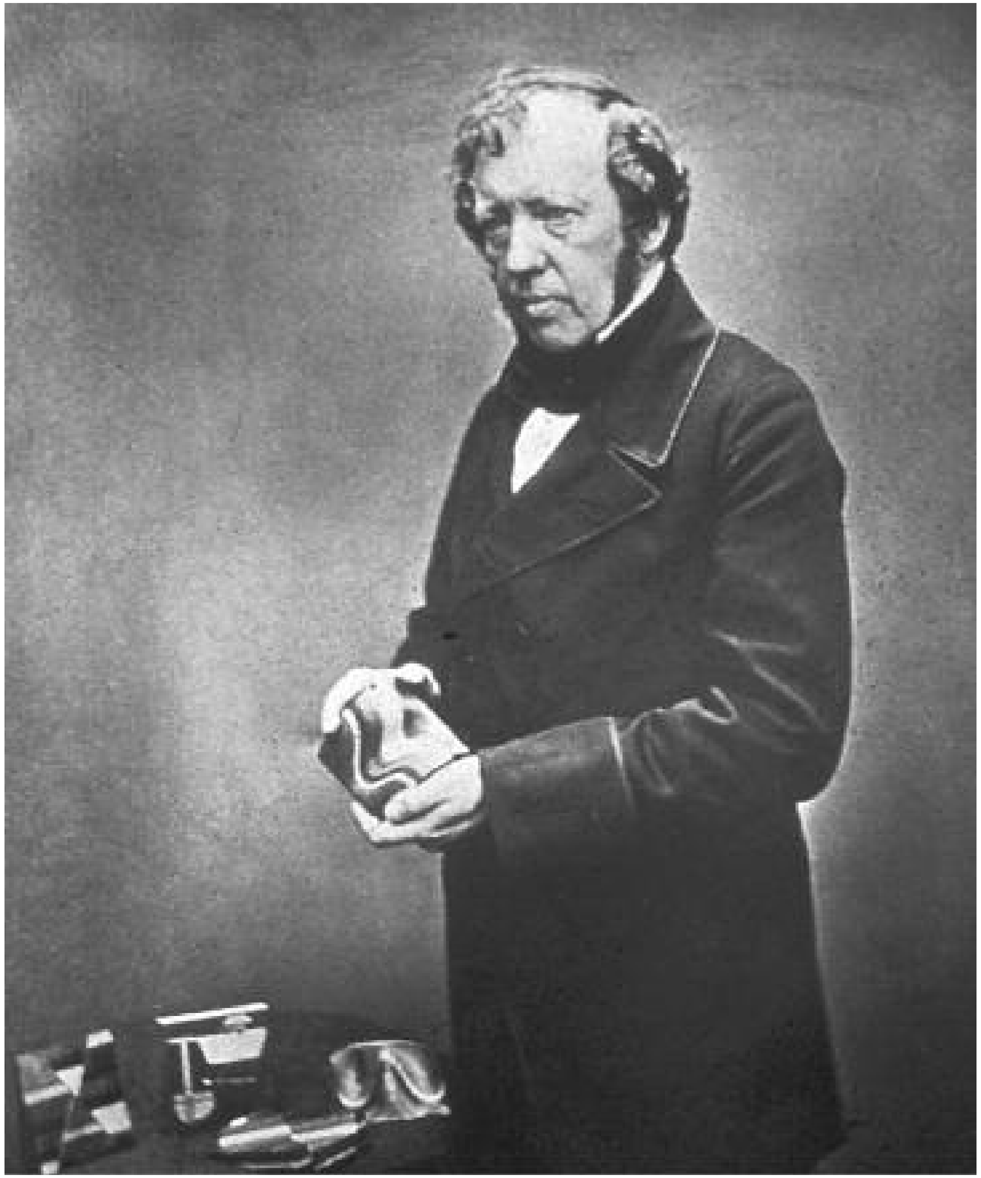
Killhope Lead mining Museum is understood to hold the only set of 'Sopwith models' housed in the North Pennines. The set is especially fine, including the original explanatory notes sold with the models.

Mine models:

During the 1960s and 1970s the British Steel Corporation employed mine models to visualise underground developments at their North Pennine fluorspar mines. The models were constructed from metal rods, coloured to depict stratigraphical horizon, vein intersections etc. They were built, and kept up to date, by skilled professional model makers working in conjunction with the working plans of the mines. The models of the workings at Blackdene Mine, Weardale, and Beaumont (Allenheads) survive today in the North Pennines.

The **Blackdene Mine** model, which depicts the 20th Century workings of this mine, together with parts of early operations, is on display at the Weardale Museum, Ireshopeburn.

The **Beaumont (Allenheads) Mine** model, which incorporates parts of the 19th Century workings of Allenheads Mine, together with the unsuccessful attempts at re-opening during the 20th Century, is held at the Allenheads Heritage Centre.



"Thomas Sopwith with a selection of his wooden geological models" © BGS, NERC.

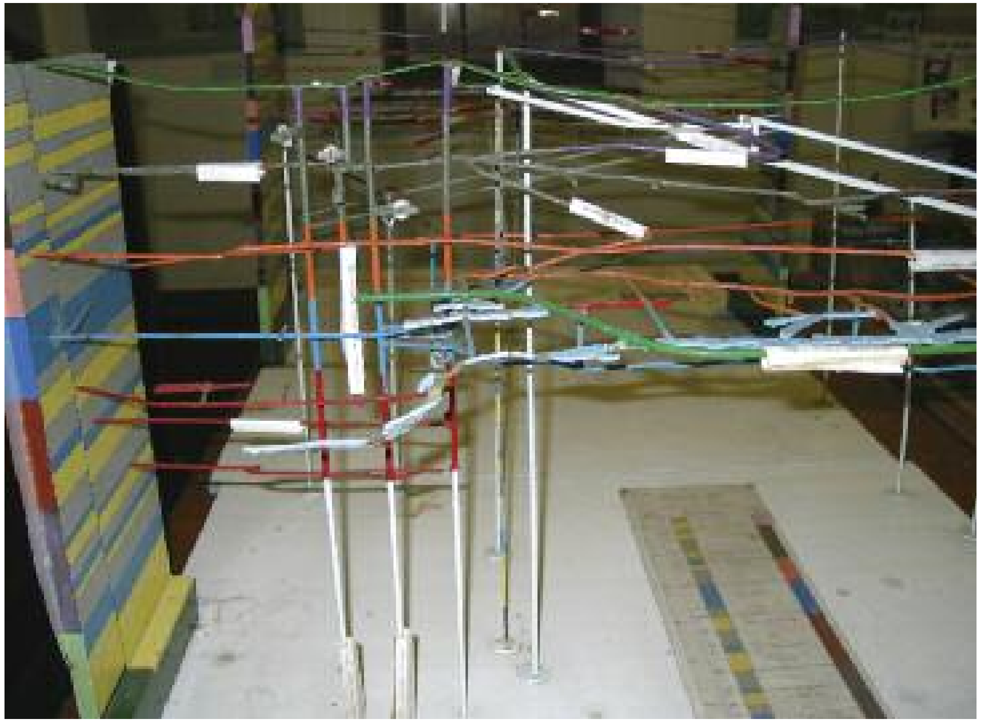
Wider importance

The importance of these models spans the interests of geology, mining history and the development of geological understanding of the North Pennine mineral deposits.

Conservation issues

The Blackdene Mine model is in generally sound condition, though could benefit from some comparatively minor restoration, mainly to its paintwork. As it is currently displayed, the model is accompanied by some very brief explanatory notes, though there is no detailed interpretation.

The Beaumont Mines model has recently been professionally restored and will form part of the interpretative displays soon to be opened at the Old Blacksmith's Shop, Allenheads.



British Steel's mine model for Allenheads. © Elizabeth Pickett

Geological Archives

In this section the various archival sources available to those who might wish to study, conserve or interpret geodiversity are considered under the headings 'Documentary Archives' and 'Materials Collections'.

Documentary Archives

The literature sources listed here comprise the most comprehensive and authoritative reviews and summaries of the geodiversity. References to the huge literature of more specific and detailed individual accounts and interpretations will be found in the references cited in these.

Of prime importance in considering the geology of any part of Great Britain is the huge volume of descriptive and interpretative information, both published and unpublished, available from the British Geological Survey (BGS). The principal sources of BGS information relevant to the AONB are considered below, before commenting on other major data sources.

The British Geological Survey

The British Geological Survey (BGS) has an incomparable archive of information and materials collections relating to the North Pennines, dating back to the earliest years of geological mapping and research in this area in the final quarter of the 19th Century. The North Pennines has been a focus for studies by BGS (and its predecessors) over the succeeding years.

Information sources held by BGS include original field maps (field slips), published maps, memoirs, reports, open-file reports, borehole records, mine plans, fossils, rock samples, thin sections, hydrogeological, geochemical, geophysical and geotechnical data and photographs.

The following BGS publications provide information on the surface geology of the AONB:

Geological maps

The following BGS geological maps cover, or include, parts of the AONB

1:63 360 scale

Sheet 32, Barnard Castle, Solid and drift*, 1969; Solid with drift, 1969

1:50 000 scale

Sheet 18, Brampton, Solid geology, 1976; Solid and drift, 1980
Sheet 19, Hexham, Solid geology, 1975
Sheet 20, Newcastle upon Tyne, Solid and drift, 1992; Solid with drift, 1989
Sheet 24, Penrith, Solid and drift, 1974; Solid with drift, 1974
Sheet 25, Alston, Solid and drift, 1973
Sheet 26, Wolsingham, Solid and drift, 1977; Solid with drift, 1977
Sheet 31, Brough under Stainmore, Solid and drift, 1974; Solid with drift, 1974
Sheet 40, Kirkby Stephen, Solid and drift, 19
(*Geological maps are produced in a variety of styles, appropriate to the area concerned.

'Solid' maps show only the solid (bedrock) geology in colour. Drift deposits may be omitted or shown only as uncoloured areas indicated by pecked lines; small drift areas may not be indicated.

'Solid and drift' maps show both the solid and the drift geology, merged to represent the surface geology. Geological lines and symbols for the surface outcrops of both solid and drift deposits are shown, but details of solid deposits that are overlain by drift are normally abridged.

'Solid with drift' maps also show the solid and drift geology; but the drift deposits are uncoloured or only have coloured outlines. The buried geological boundaries of the solid deposits occurring beneath the drift are shown in full.

1:10 000 and 1:10 560 scale

Details of the original geological surveys at these scales are listed on editions of the 1:50 000 or 1:63 360 scale geological sheets. Copies of the fair-drawn copies of earlier geological surveys may be consulted at BGS libraries at Edinburgh and Keyworth and at the BGS London Information Office in the Natural History Museum, South Kensington, London. Copies of these maps may be purchased directly from the British Geological Survey as black and white dyeline, Xerox or photographic copies.

BGS books and reports

Full details of the various BGS books, memoirs and reports relevant to the North Pennines are listed in the reference section.

The following British Geological Survey Memoirs describe the geology of the North Pennines:

Brampton (Trotter and Hollingworth, 1932)

Newcastle upon Tyne (Mills and Holliday, 1998)

Penrith (Arthurton and Wadge, 1981)

Brough under Stainmore (Burgess and Holliday, 1979)

Barnard Castle (Mills and Hull, 1976)

Geology of the Northern Pennine Orefield Vol 1 Tyne to Stainmore (Second edition) (Dunham, 1990)

Geology of the Northern Pennine Orefield Vol. 2 Stainmore to Craven (Dunham and Wilson, 1985)

Details of more specialised geological information, including small scale maps, applied geological maps, geophysical maps, hydrogeological maps, groundwater vulnerability maps, and maps of geochemical data, available from the British Geological Survey, can be accessed on the BGS Web Home Page at http://www.bgs.ac.uk

Soil Survey

Specialised information on soil character, properties and classification for the AONB may be obtained from publications of the Soil Survey of England and Wales, now the Soil Survey and Land Research Centre, www.silsoe.cranfield.ac.uk/nsri

Conserved and protected geological sites and features

Information on geological Sites of Scientific Interest (SSSIs) within the AONB is held by Natural England. Details may be obtained from Natural England. www.naturalengland.org.uk

Information on RIGS sites within the Cumbrian part of the AONB is held by Cumbria RIGS.

Information on Local Geodiversity Sites is held by the county Wildlife Trusts though at the time of writing such sites are being reviewed.

Information on other geologically significant sites across North East England is held at the Great North Museum (formerly the Hancock Museum), Newcastle upon Tyne.

Information on Durham County Geological Sites is held by Durham County Council.

Mine plans

Centuries of metal mining in the AONB have produced a substantial legacy of mine plans and related records. These documents, which contain huge amounts of often unique geological information, are an important element in the area's geological heritage, and thus its geodiversity.

At present there is no central repository of metal mining information in the UK. Large and important collections of such records are known to be cared for by a number of organisations, though many original, and thus unique, mine plans and associated documents are known to be in private hands. These are often difficult or impossible to trace or access. Plans are unknown for many mines, even where they are believed to have been maintained during the life of the mine. Many plans are known to have been lost or destroyed.

The County Record Offices of Cumbria, Durham and Northumberland have the most significant collections of mining information relating to the AONB. Other bodies holding mine records are the North of England Institute of Mining and Mechanical Engineers, based in Newcastle, the Edinburgh office of the British Geological Survey and the Burton on Trent office of The Coal Authority.

Materials collections

Significant collections of geological specimens from the AONB are mostly held by museums. Within northern England important collections of specimens derived from the AONB are held by the Great North Museum (formerly known as the Hancock Museum), (Newcastle upon Tyne); Sunderland Museum and Art Gallery; Tullie House Museum, (Carlisle); Killhope Lead Mining Museum, (Upper Weardale) and the Weardale Museum, (Ireshopeburn, Weardale). Beyond the region, extremely important collections are held by Great Britain's three national museums: the Natural History Museum (London): the National Museum of Wales (Cardiff) and the Royal Scottish Museum (Edinburgh). Significant collections of North Pennine specimens are also to be found in the Hunterian Museum (University of Glasgow); Manchester University Museum; Oxford University Museum and the Sedgwick Museum (University of Cambridge). In addition, important collections of North Pennine specimens are held by BGS and by the Department of Earth Sciences, University of Durham. There are also a few significant private collections of geological materials, mainly minerals, from the AONB, though these may be difficult to trace and access.

Geological Societies

Geological societies have long played, and continue to play, an important role in many aspects of geodiversity. The following geological societies are currently active within northern England and take an interest in the geology of the AONB:

Cumberland Geological Society

Cumbria RIGS

Natural History Society of Northumbria (Geology Section)

North East Geological Society

Open University Geological Society

Russell Society

Westmorland Geological Society

Yorkshire Geological Society

Although not a geological society, the ***Friends of Killhope***, organises events some of which involve aspects of the area's geology.

Most of these societies arrange programmes of lectures and field meetings, several of which relate to aspects of the geology of the AONB.

Geological societies perform an important role in communicating knowledge and expertise both to their members and the wider public. Several societies publish journals and newsletters in which are reported original observations or reviews of local geology. Especially noteworthy are the many original papers which have appeared over many years in the *Proceedings of the Yorkshire Geological Society.*

There is substantial scope for involving local geological societies in geodiversity conservation and interpretation work within the AONB.

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Glossary

Adit	Horizontal, or nearly horizontal tunnel or mine entrance
Ammonoid	A subclass of molluscs with coiled shells belonging to the class Cephalopoda
Anticline	Arch-shaped fold of rocks, closing upwards
Armour-stone	Large stone block used in coastal defence and other engineering works
Aureole	Area surrounding an igneous intrusion affected by metamorphic changes
Batholith	A large body of intrusive igneous rock with no visible floor
Bituminous	Rich in hydrocarbons or bitumen
Bivalve	Aquatic molluscs of the class Bivalvia, characterised by paired shell valves.
Blanket bog	An extensive area of peat bog
Bouguer anomaly	A gravity anomoly calculated after corrections for latitude, elevationand terrain.
Brachiopod	A phylum of solitary marine shelled invertebrates
Braided rivers	A river consisting of a number of small channels separated by bars
Breccia	Coarse-grained clastic sedimentary rock consisting of angular fragments of pre-existing rocks
Brockram	A term used in NW England for breccias and conglomerates of Permo-Triassic age
Calc-silicate	A group of minerals consisting of calcium silicates
Chert	A dense, very hard rock composed of extremely fine-grained silica.
Chronostratigraphy	The standard hierarchical definition of geological time units
Conglomerate	Coarse-grained clastic sedimentary rock composed of rounded or subrounded fragments of pre-existing rocks
Conodonts	An extinct group of microscopic marine animal fossils, composed mainly of calcium phosphate, and which commonly resemble fish teeth and worm jaws.
Continental shelf	The gently sloping offshore zone, extending usually to about 200 metres depth
Crinoid	Crinoids, or 'sea lillies', are marine animals composed of calcareous plates, belonging to the phylum Echinodermata
Cross-bedding	Internally inclined layers in a rock related to the original direction of current flow
Cupola	A dome-shaped offshoot rising from the top of a major igneous intrusion
Desiccation cracks	Polygonal cracks formed in a sediment as it dries out in a terrestrial environment, also known as shrinkage cracks
Displacement	The relative movement on either side of a fault plane
Doline	A steep-sided enclosed depression in a limestone region
Dolomitic limestone	A limestone containing a high concentration of the mineral dolomite
Dry valley	A valley produced by running water but which is presently streamless
Dyke	Discordant, sheet-like bodies of intrusive igneous rock in a vertical, or near-vertical orientation
Evaporites	Sedimentary deposit of minerals formed by natural evaporation
Fault	A fracture in rocks along which some displacement has taken place
Feldspar	A group of rock-forming minerals consisting of silicates of aluminium, sodium, potassium, calcium and more rarely barium
Felsite	A general term used to denote fine-grained igneous rocks
Gangue	Generally valueless mineral or rock which accompanies an ore
Gastropod	Molluscs belonging to the class Gastropoda, usually with coiled shells
Gouge	Broken rock, often shale or clay, in a mineral vein or between fault planes
Graptolite	A group of extinct colonial marine organisms. Generally placed in the phylum Chordata, but sometimes regarded as Coelenterata. They consist of one or more branches or stipes in which individuals in the colony occur in rows
Greywackes	A sandstone containing a high proportion of silt, clay and rock fragments in addition to quartz grains
Hornfels	A fine-grained rock that has been partly or completely recrystallised by contact metamorphism

Inlier	An outcrop of older rocks surrounded by those of younger age
Joints	A fracture, or potential fracture, in a rock adjacent to which there has been no displacement
Lamprophyre	A group of intrusive igneous rocks characterised by abnormally high contents of silicate minerals such as biotite, hornblende and augite, with generally small amounts of feldspar
Lapilli-tuff	A compact rock composed of small pieces of lava rounded during eruption
Lithology	The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents
Magma	Molten rock
Magnetic anomaly	The value of the local magnetic field remaining after the subtraction of the dipole portion of the Earth's field
Metamorphism	Change in the mineralogy and structure of a rock as a result of the effects of heat and/or pressure
Monocline	A one-limbed flexure on either side of which the strata are horizontal or dip at only low angles
Mountain building	The complex series of geological processes which create mountains
Nunataks	An isolated mountain peak projecting from an ice sheet
Ostracod	Small arthropods belonging to the subclass Ostracoda, having a twin shell
Outlier	A remnant of a younger rock surrounded by older strata
Palaeomagnetic	The magnetic characteristics of a rock formed in the geological past
Pegmatite	Igneous rocks of especially coarse grain size
Phenocryst	Large crystals, usually of near perfect shape, embedded in a fine-grained matrix in igneous rocks
Phreatic	Volcanic eruptions generated by the interaction between hot magma and surface or ground water
Porphyritic	The term applied to igneous rocks which contain isolated crystals, or phenocrysts, larger than those forming the main body of the rock
Radiometric dating	The method of determining the geological age by measuring the relative abundance of parent and daughter isotopes in rocks
Rendzina	A brown earth soil of humid or semi-arid grassland that has formed over calcareous parent material.
Rottenstone	Any highly decomposed but still coherent rock
Sedimentary rocks	Those rocks formed by the accumulation of fragments from the wasting of previous rocks or organic materials, deposited as layers of sediment
Sill	A tabular igneous intrusion with concordant contacts with the surrounding wall rocks
Sink hole	see doline
Statigraphy	The definition and description of the stratified rocks of the Earth's crust
Streak	The name given to the colour of the powder of a mineral or rock
Supergene	Alteration formed near the surface
Syncline	A concave-upwards fold with the youngest rocks in the centre
Tailings	Fine-grained waste from mineral processing operations
Throw	The amount of displacement on a fault
Tonstein	A rock, composed mainly of the mineral kaolinite, typically found as thin lasyers in coal-bearing sequences of rocks. Tonsteins may have been formed by the decomposition of volcanic ash-falls.
Trilobite	Extinct marine arthropods characterised by having a segmented oval body divided into three segments
Tufa	A porous or cellular deposit of calcium carbonate deposited from lime-rich springs
Tuff	A rock formed of compacted volcanic fragments
Turbidity current	A dense sub-marine flow of mixed water and sediment, capable of very rapid movement
Unconformity	A substantial break in the succession of stratified sedimentary rocks following a period when no deposition was taking place
Volcaniclastic	A rock containing volcanic fragments in varying proportions
Xenolith	A foreign inclusion in an igneous rock

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