North Pennines Geology and Landscape

2. Introduction to the North Pennines

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- A simplified geology of the North Pennines
- Landscape processes in the North Pennines
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2. Introduction to the North Pennines

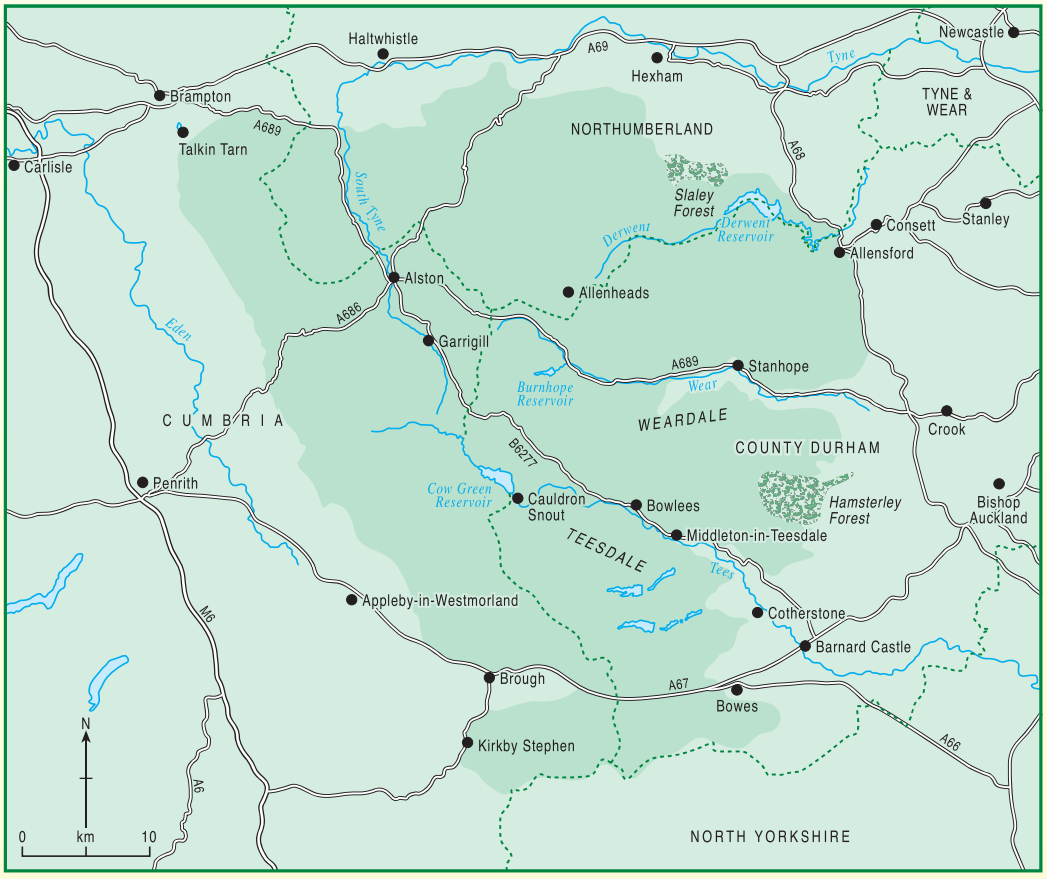
The North Pennines Area of Outstanding Natural Beauty and European Geopark

The North Pennines in northern England, spans parts of County Durham, Cumbria and Northumberland. It was designated an Area of Outstanding Natural Beauty (AONB) in 1988. Map 2 shows the North Pennines AONB

An AONB is a Protected Landscape, with the primary purpose of designation being the conservation and enhancement of natural beauty. In pursuing this primary purpose, account is taken of the economic and social needs of the local community.

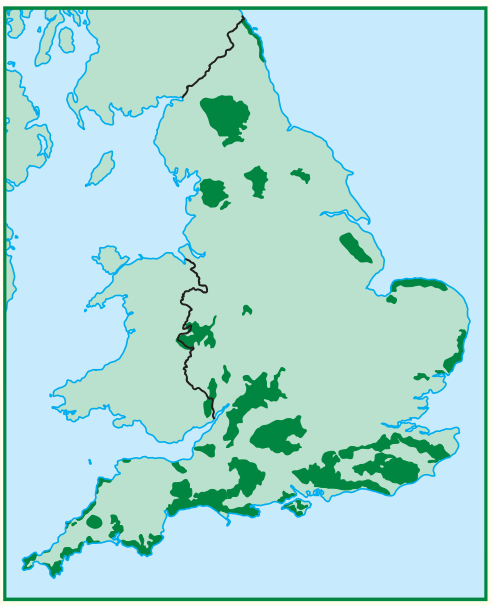
The North Pennines is the second largest of 40 AONBs in England and Wales and is one of the most remote and unspoilt places in England (Map 3). It is characterised by high, open moorland, dramatic dales, waterfalls, stone-built villages, and communities linked to the land through mining, quarrying and farming. The North Pennines is a haven for wildlife and has 40% of the UK's upland hay meadows, supports 22 000 pairs of breeding waders and has over 80% of England's black grouse population.

But it is the rocks that are the building blocks of the North Pennines and they tell the story of moving continents, tropical seas, molten rock, minerals and ice sheets. The geology of the area is of worldwide significance. The North Pennines has the accolade of being Britain's first European Geopark. Geoparks are places with outstanding Earth heritage where special effort is made to look after geological features



Map 2: North Pennines Area of Outstanding Natural Beauty (AONB) & Geopark

and them to support sustainable development. There are currently 34 European Geoparks, which are part of the European Geoparks Network. All European Geoparks are part of the larger UNESCO Global Geoparks Network.



Map 3: Areas of Outstanding Natural Beauty in England.

Geology of the North Pennines

The landscape we see today represents hundreds of millions of years of natural processes involving the underlying rocks and the mineral deposits they contain.

Geologists divide geological time up into geological periods. A lot of geological periods are represented in the North Pennines, the most important being the Carboniferous and the Quaternary. See Figure 1 and Map 4.

The rocks in the North Pennines are mainly from the Carboniferous Period of Earth history, which was between 350 and 300 million years ago. Rocks from other periods are also represented and have had an important influence on the landscape and economic activity of the North Pennines.

The key geological events of the North Pennines that have created the spectacular landscape seen today are explained below.

The Oldest Rocks

The oldest rocks and those that underlie most of the North Pennines at depth are mostly slates, shales and volcanic rocks that formed between 500 and 420 million years ago in the Ordovician and Silurian Periods (See Figure 1). These rocks were deposited at the edge of a wide ocean known as the Iapetus Ocean. The ocean closed at round 420 million years ago when northern England (then part of the northern edge of a continental plate) collided with a huge continent, which contained Scotland and much of North America.

As the two continents collided through the process known as plate tectonics, enormous volcanic eruptions occurred, which lasted for around 12 million years. Stresses built up in the continental plates as they collided and this led to the rocks being squashed, folded and partly baked. (See the Rock Box). These Ordovician and Silurian rocks are only exposed in the North Pennines at Cronkley Fell (Teesdale) and at Knock Fell and Cross Fell between Melmerby and Brough at the foot of the Pennine Escarpment.

The Cross Fell exposures contain examples of the oldest fossils found in the North Pennines. These are Trilobites. They were marine arthropods, which lived on the seafloor during the Ordovician Period and were preserved in the sediments, turned into rock and then folded and baked. (See the Rock Box).

The Hidden Granite

Hidden beneath the sedimentary rocks that form much of the North Pennine landscape is a granite that rose as molten rock from deep in the earth approximately 400 million years ago. Known as the Weardale Granite, its presence was identified in 1961 from the drilling of a 390 m borehole at Rookhope. Although the formation of the granite is not thought to be responsible for the mineralisation of the North Pennines it has had an important influence.

Most granites are less dense than other igneous rocks in the Earth's crust and hence tend to be relatively buoyant. As a result, much of the North Pennines has remained as an upstanding area known as the Alston Block. The periphery of the area is delimited by faults – fractures in the Earth's crust. A good example is the Pennine Fault that forms the prominent escarpment between the North Pennines and the Eden Valley.

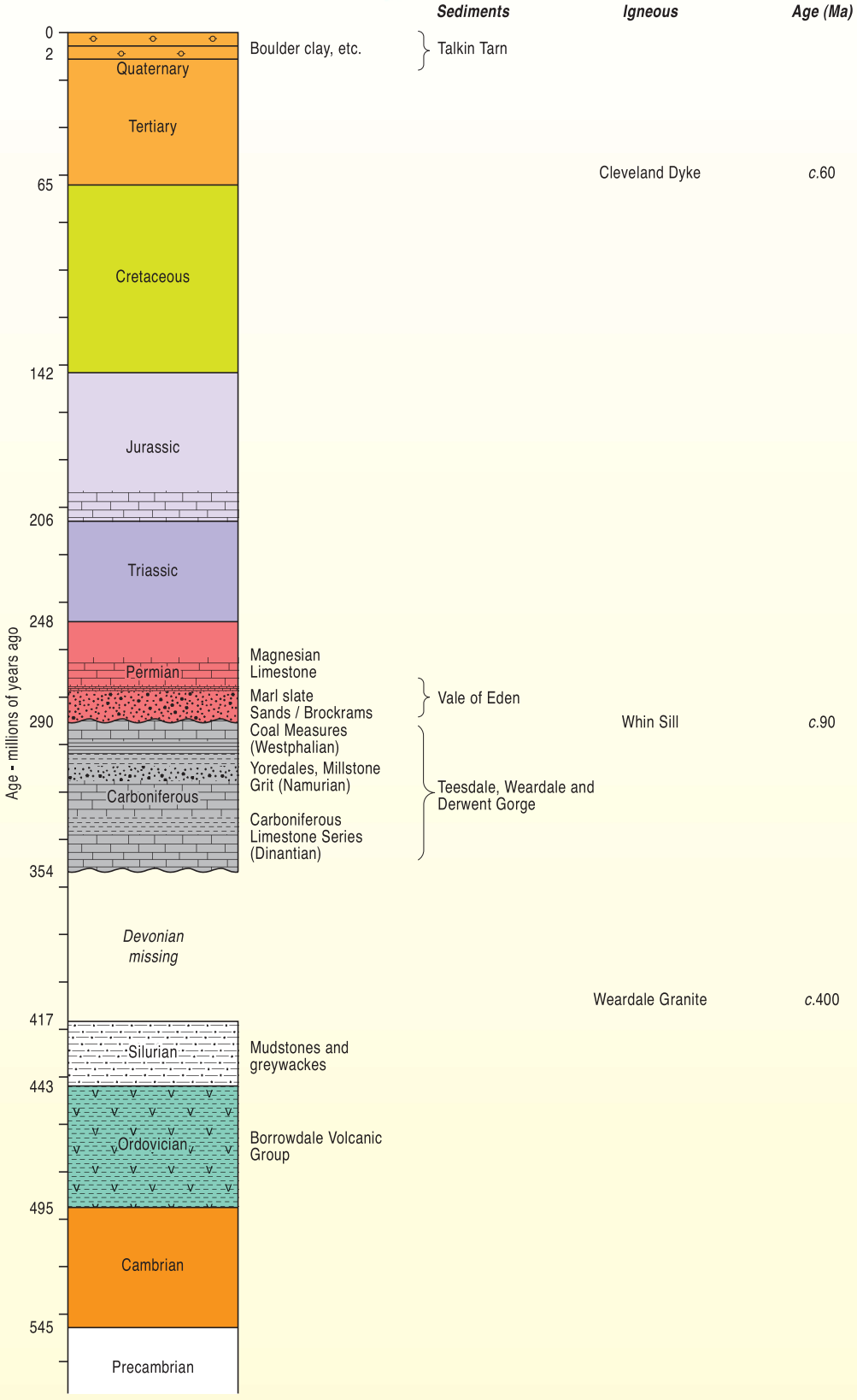
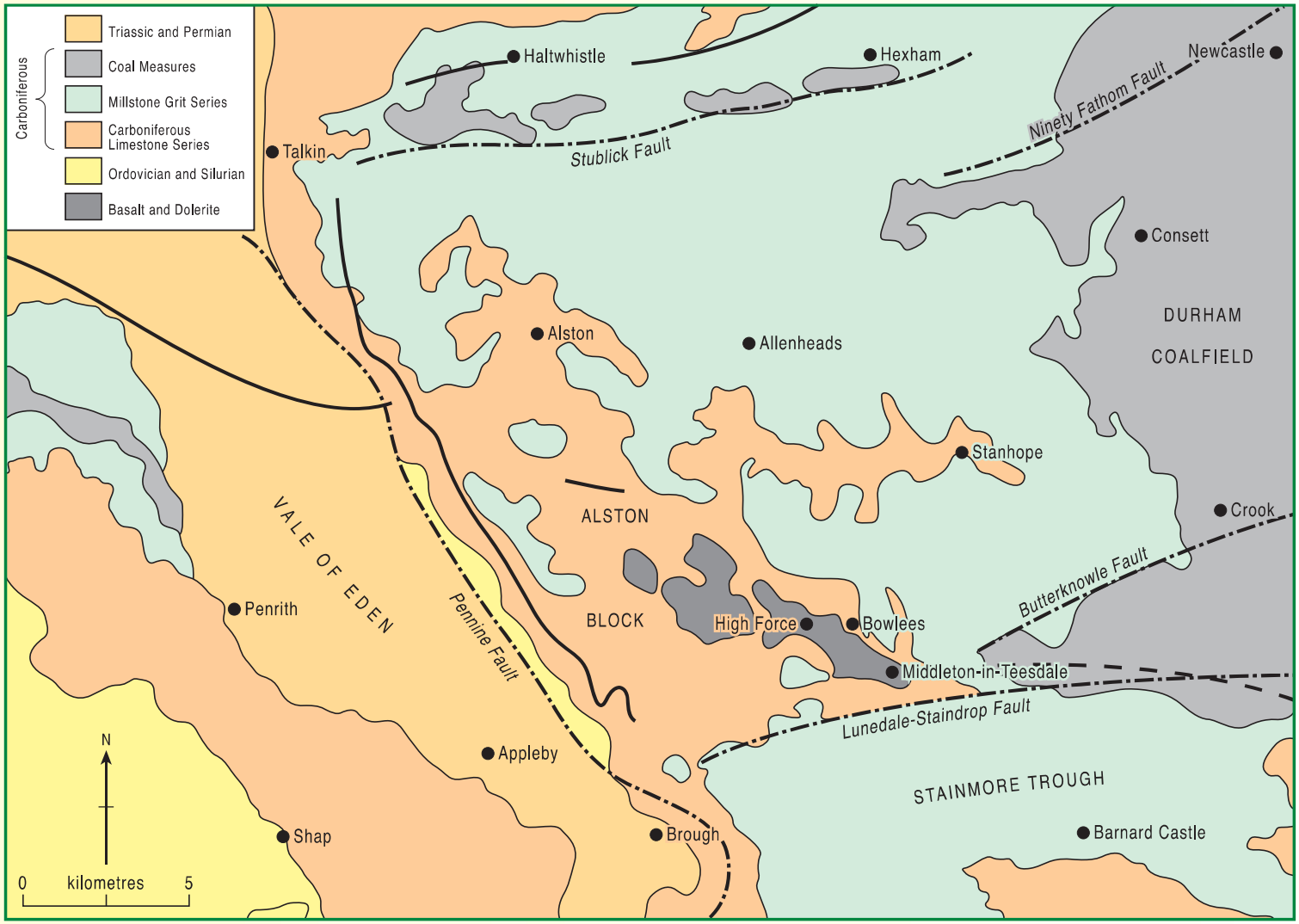


Figure 1: Geological time



Map 4: General geological map of the North Pennines area

Layers and Cycles

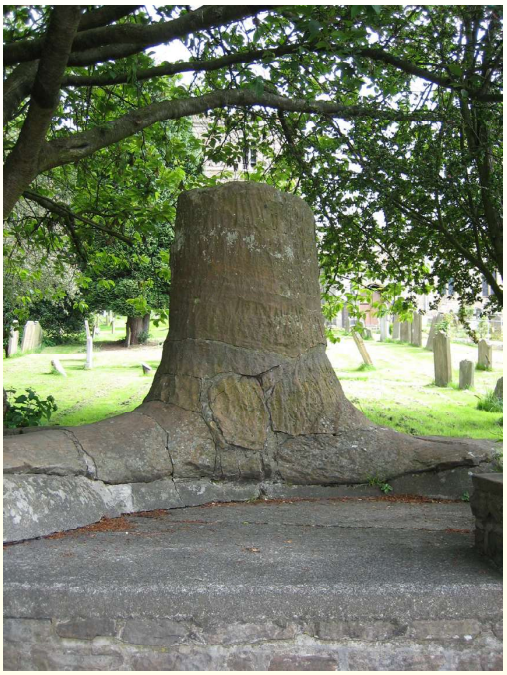
Between 350 and 300 million years ago the landmass that was to become the UK was positioned at the equator. During this geological time period, known as the Carboniferous, the North Pennines was periodically covered by large rainforests, vast river deltas and warm tropical seas as sea levels rose and fell.

Warm tropical seas: The Carboniferous seas were full of marine animals such as corals, sponges, crinoids, brachiopods and bivalves. The remains of these organisms – many of them long extinct – accumulated on the sea floor to form a limy ooze. The ooze compacted and hardened over millions of years under the weight of layers above, eventually forming the dark grey limestones characteristic of the North Pennines. The limestones are grey in colour because they contain mud and silt washed off the nearby landmasses.

Rivers and Deltas: The warm tropical seas that covered much of the North Pennines were periodically inundated by huge influxes of sand, silt and mud. Large rivers draining the land transported the sediment to the coast where the rivers formed huge deltas. In time, the deltas built far out into the sea. The sand, silt and mud settled out on the sea floor, burying the coral reefs and other marine life and eventually hardening into sandstone, siltstone and mudstone (also sometimes called shale).

Tropical Forests: Large rainforests and swamps flourished on the delta tops. The swamps were very similar to those found on the Mississippi and Niger deltas today. The Carboniferous forests covering the North Pennines were the ancestors of modern club mosses, ferns and horsetails. However they differed substantially in that many of the club mosses grew up to 30 m high (e.g. Lepidodendron). We can see examples of this great forest today – in the area's coal seams and the many plant fossils in local sandstones (Photograph A).

Cyclicity in the Carboniferous, perhaps more discrete than the different fossils and sediment types is the repetition of limestone, mudstone (shale), sandstone and coal that happened many times. This repetition, or cyclicity, is known to geologists as a cyclothem. The position in the cyclothem and the order of the layers allows a geologist to determine the order of events



Photograph A: Stanhope Fossil Tree

and the relative sea level changes. The younger rocks are laid down on top of older rocks, so fossiliferous limestone lying on top of a coal seam identifies that the sea level rose and flooded a forest. See Figure 2.

These cyclothems have a profound impact on the North Pennines landscape. The sandstones and limestones are hard, resistant rocks, whereas the softer mudstones (shale) and coal layers are less resistant to erosion and wear away easily. This difference produces the characteristic terraced hillsides of parts of the North Pennines.

The Whin Sill

The Whin Sill is one of northern England's most impressive and famous geological features. The hardness of the rock makes it very resistant to erosion and it now stands out as cliffs and waterfalls in Teesdale and along the North Pennine escarpment (e.g. High Cup Nick). The Whin Sill is a tabular layer of igneous rock that formed 295 million years ago when magma rose from deep within the Earth at temperatures of over 1000°C. The magma did not erupt at the surface but was instead forced between the layers of Carboniferous sedimentary rocks. See Figure 3.

As the magma cooled it solidified into a vast sheet called a sill, which can reach up to

Figure 2: An artistic representation of how a cyclothem is formed in the North Pennines. (© Elizabeth Pickett)

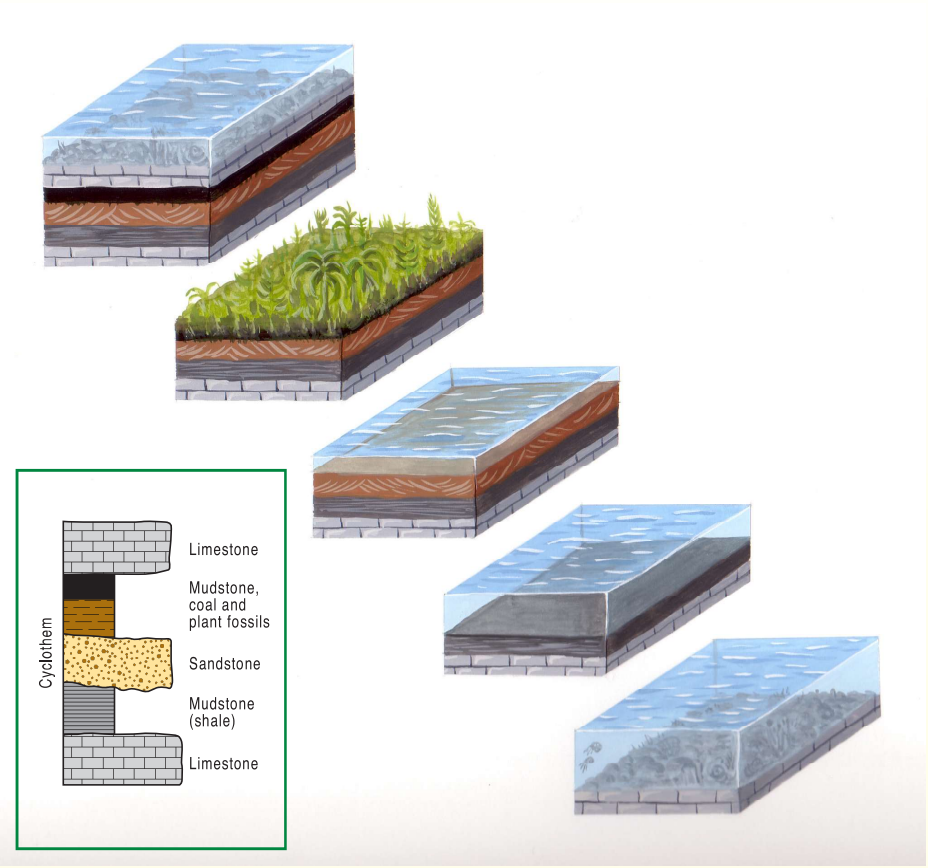
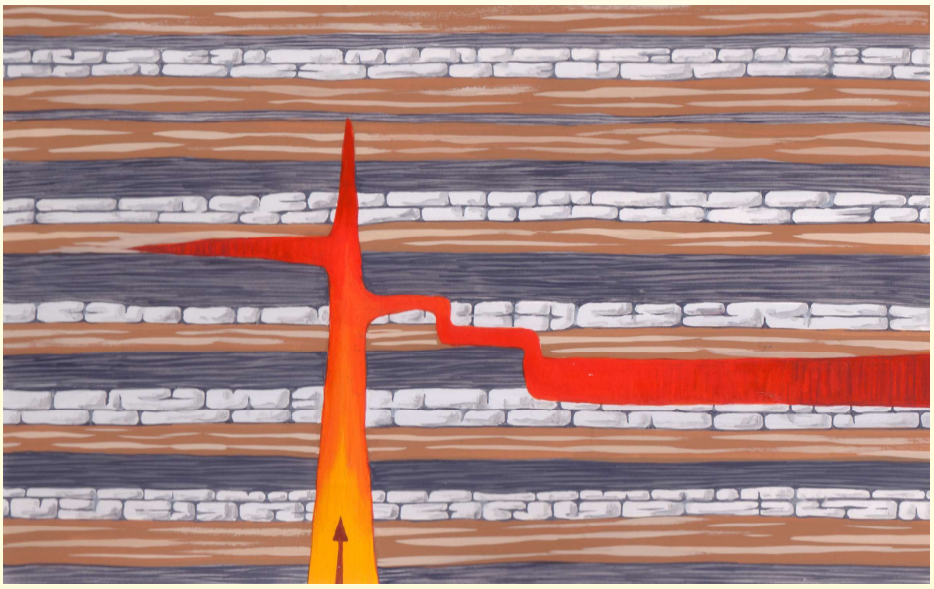


Figure 3: The Whin Sill between layers of Carboniferous sedimentary rocks. (© Elizabeth Pickett)



Age	Name	Environment of deposition
Lower Triassic	St. Bees Sandstone	Bright red sandstone - ancient rivers
Upper Permian	Eden Shales and Evaporites	Dull red shales and white evaporites - desert lakes
Lower Permian	Penrith Sandstone	Dull-brick red sandstone - desert dunes
Lower Permian	Brockram	Poorly sorted red and grey breccias and conglomerates - flash floods

Table 1: The Permian and Triassic rocks found in the Vale of Eden and along the Pennine Escarpment

70 m thick. It is made of a hard black/dark grey, crystalline rock called dolerite. As the magma cooled it started to contract, producing vertical cracks along which the rock breaks into rough columns. This feature is known as columnar joining.

The intrusion of the Whin Sill into the Carboniferous rocks caused them to be baked and altered, a process known as metamorphism. This process is particularly apparent in Upper Teesdale, (e.g. Cauldron Snout) where limestone turned into a distinctive white crystalline marble, known as 'Sugar Limestone'.

Hot and arid

In the Eden valley and northwards along the Pennine escarpment, red sandstones are used as a common building stone in many of the villages. These rocks form part of a sequence (See Table 1) of rocks that were deposited when the area was once a hot, arid desert.

Between 290 and 206 million years ago during the Permian and Triassic time periods northern England lay just to the north of the equator, in a similar position to the Sahara Desert today. During the Permian Period the North Pennines was a hot and arid place with large desert dunes, rocky landscapes and some flash floods. During the Triassic Period the climate became more humid and flash floods and seasonal rivers spread across the desert plains.

The red sandstones (Penrith and St Bees Sandstones) are commonly used as building stone as they can be easily worked and are reasonably resistant to weathering. The mining and quarrying of gypsum beds within the Permo-Triassic rocks, for the manufacture of plaster products, is a long-established industry. A large modern processing plant at Kirkby Thore is a conspicuous element in the landscape today.

Minerals in the Hills

The Northern Pennine Orefield is world famous for its remarkable array of lead, zinc and iron ores, fluorite and barium minerals. The mining of the mineral veins and deposits has had a profound impact on the environment with mining activity possibly dating back at least 2000 years.

The mineral veins of lead ore and other minerals formed about 290 million years ago when hot mineral-rich waters flowed through cracks and fissures in the Carboniferous rocks of the North Pennines. As the fluids cooled, the dissolved minerals crystallized within the cracks, forming near-vertical mineral veins. Sometimes the fluids reacted with the Carboniferous limestone on the sides of the cracks, altering the rock and forming mineral deposits known as 'flats' (See Photograph B).

As well as the ores of lead (galena) and zinc (sphalerite) the mineral veins and flats contain many other minerals. Some of the world's finest and most spectacular specimens of minerals such as fluorite, witherite, barytocalcite and alstonite have come from the North Pennines. Examples of these minerals can be found in most of the world's major mineralogical collections. Visit Killhope or Nenthead lead mining museums

Photograph B: West Rigg open-cut, Westgate, Weardale

to see some superb specimens of the area's minerals. Also use the rock box and mineral / rock dials associated with this education pack.

Landscape processes on the North Pennines

More recently in geological time, about two million years ago, the world climate cooled and a series of ice ages began. The landscape of the North Pennines owes much of its character to the action of ice and meltwater during the last ice age. This last ice age was at a maximum 20 000 years ago. During this time the North Pennines was covered by a 1 km-thick ice sheet that streamed from west to east over the landscape.

The ice sheet rounded and deepened the valleys that already drained the North Pennines. This is best seen in Upper Teesdale and at High Cup Nick. (Photograph C) The ice also deposited great volumes of material called 'glacial till'– made up of clay, gravel and boulders. The glacial till has been moulded and streamlined in some places to form rounded, elongated hills called drumlins (Photograph D). These too can be seen in Teesdale and are especially well formed in the Eden Valley. Rivers within the ice also

Photograph C: High Cup Nick

deposited sediments to form ridges called eskers; an excellent example can be seen at Busk in Cumbria. As the climate warmed towards the end of the ice age, large volumes of meltwater created drainage channels throughout the North Pennines, changing the detail of the landscape (Photograph E).

Photograph D: Holwick drumlins

Photograph E: Meltwater channel

Since the last ice age the processes of erosion and weathering have continued to work on the landscape of the North Pennines. The rivers that drain the area – the Tees, Wear, Derwent, South Tyne and the East and West Allens - continue to rework the material left by the ice (Photograph F). The tributary rivers strive to cut down to the main river valleys, which are now lower as a result of the glaciation. This has created steep sided valleys. The rivers also produce some of the most dramatic features of the North Pennines landscape - the waterfalls. The best known and most dramatic waterfalls are in Teesdale where the River Tees crosses the Whin Sill forming Cauldron Snout, High Force and Low Force (Photograph G) . Smaller waterfalls occur across the North Pennines where the rivers cross rocks of differing hardness such as at Ashgill Force.

Photograph F: River Tees

Photograph G High Force

The processes of weathering have also influenced the landscape. Freeze-thaw action has exploited the exposed rock surfaces and solution weathering has worked on the limestone rocks to play its part in the formation of limestone pavement, cave systems and natural bridges (Photographs H and I).

Human use of the North Pennines landscape

People have lived in the North Pennines for around 10,000 years and had a dramatic effect on the landscape. Early settlers would have found a landscape of wooded valleys. The woodland continued to flourish until about 5000 years ago when early farmers began to fell the trees. Gradually the forest was cleared by farming, creating the meadows, grassland and moorlands we see today. However, it is in the last 200 years that people have had the most impact on the landscape through farming, lead mining and quarrying.

Photograph H Limestone pavement at North Stainmore, Cumbria

Farming has been responsible for the removal of the woodland of the North Pennines. Since Neolithic Times woodland has been felled to create clearings for livestock to graze. By the Middle Ages hay meadows were common-place with animals being moved to higher ground during the summer months. The hay grown during the summer was used to feed the animals over the winter. With the intensification of farming during the 20th century hay meadows have been replaced with fast growing rye grass. Today the North Pennines AONB Partnership's Hay Time project will restore and enhance many of the remaining hay meadows and harvest seed to spread on sites that have lost their special meadow plants (Photograph J).

The mineral resources of the North Pennines have been exploited since Roman times. Many mineral products have been mined, including ores from copper, iron, lead, and zinc and minerals such as barytes, barytocalcite, fluorspar

Photograph I: A natural bridge, God's Bridge

Photograph J: Hay meadow

and witherite. It was during the 1800s that lead mining reached its peak. Lead mining has not only influenced today's landscape with its physical remains but it has also influenced the pattern of local settlement. The farmer-miners established smallholdings at very high altitudes crating a patchwork of small walled enclosures with cottages and farmsteads in the upper dales. The North Pennines was one of the most productive lead mining areas in Europe during the 18th and 19th centuries. (Photograph K)

The area's long history of mineral extraction has left the landscape littered with abandoned quarries as well some active ones. The main rocks quarried are limestone, dolerite from the Whin Sill and sandstone. The limestone and dolerite are used as roadstone and the sandstone for building, paving and walling (Photograph L).

Photograph K: Smelt mill

Photograph L: Quarrying in the Great Limestone

Guide to Powerpoint presentation (see enclosed CD):

Slide 1 – The North Pennines Area of Outstanding Natural Beauty and the European Geopark

- Location – northern England spanning parts of County Durham, Cumbria and Northumberland
- Designated an 'Area of Outstanding Natural Beauty' (AONB) in 1988
- Second largest of 40 AONBs in England and Wales
- Britain's first European Geopark and a founding member of the UNESCO Global Geoparks Network

Slide 2 - Map of North Pennines AONB

Slide 3 – Map of AONBs in England and Wales

Slide 4 – Geology of the North Pennines

A simplified geology

- The North Pennines landscape is the result of natural and human influences
- The rocks of the North Pennines are mainly from the Carboniferous Period, approximately 360-300 million years ago
- Rocks from other geological periods are represented and have had a major impact on the landscape and economic activity in the North Pennines

Slide 5 – Geology map

Slide 6 – Geological time

Slide 7 – Geology of the North Pennines

The oldest rocks

- The oldest rocks in the North Pennines are slates, shales and volcanic rocks from the Ordovician and Silurian Periods (about 500 to 420 million years ago)
- These rocks formed as 2 continental plates collided.
- Sediment was deposited in the closing Iapetus Ocean and there were enormous volcanic eruptions
- These rocks can be found below the Pennine Escarpment between Melmerby and Brough and at Cronkley Fell in Teesdale

Slide 8 – Geology of the North Pennines

The Hidden Granite

- Beneath the North Pennines there is granite, known as the Weardale Granite
- The granite rose as magma (molten rock) from deep within the earth
- The granite has played an important role in forming the minerals of the North Pennines

Slide 9 – Geology of the North Pennines

Layers and cycles

- The plates of rock that form the Earth's crust are always moving! So during the Carboniferous Period the landmass that was to become the UK was positioned near the equator
- During this time the North Pennines was periodically covered with shallow, tropical seas, vast river deltas and large rainforests as sea levels rose and fell
- This cycle produced a repetition of rock types – layers of limestone, shale, sandstone and coal are repeated many times.
- These cycles are called 'cyclothems'

Slide 10 – A cyclothem

Slide 11 – Stanhope fossil tree

Slide 12 – Geology of the North Pennines

The Whin Sill

- The Whin Sill is a layer of igneous rock formed when magma rose from deep within the Earth 295 million years ago
- The magma did not reach the surface of the earth but was injected between the layers of Carboniferous rocks
- This hard, resistant rock stands out as cliffs and waterfalls in Teesdale, and along the Pennine Escarpment, particularly at High Cup Nick

Slide 13 – Geology of the North Pennines

Hot and arid

- During the Permian and Triassic Periods (about 290 – 205 million years ago) northern England had moved to just north of the Equator, in a similar position to the Sahara Desert today
- Red sandstones were formed in these hot arid conditions

- The sandstones are used for building and can be seen in many of the houses and are especially red in the Eden Valley

Slide 14 – Geology of the North Pennines

Minerals in the hills

- Minerals are naturally occurring substances with a definite chemical composition whereas rocks are a combination of different minerals. Minerals include lead ore (galena) and quartz
- The North Pennines is world famous for its minerals and the mining of minerals dates back at least 2,000 years
- The minerals formed about 290 million years ago when hot mineral-rich waters flowed through cracks and fissures in the Carboniferous sediments
- The fluids cooled and the minerals crystallised within the rocks as vertical 'veins' and horizontal 'flats'

Slide 15 – Photograph of West Rigg open-cut

Slide 16 – Landscape processes on the North Pennines

Glaciation

- The last ice age was at its most extensive 20,000 years ago
- This ice age covered the North Pennines in a 1 kilometre thick ice sheet
- Towards the end of the ice age the area may have looked similar to the way the Canadian Arctic looks today
- Landscape features left by glaciation include valleys that are wider and deeper than would be possible if eroded by just a river, features formed by material deposited by glaciers such as drumlins and eskers and meltwater channels carved as the glaciers melted

Slide 17 – Photograph of the Canadian Arctic

Slide 18 – Photographs of High Cup Nick, drumlins at Holwick, Busk esker and Teesdale meltwater channel

Slide 19 – Landscape processes on the North Pennines

Rivers

- The main rivers that drain the area are the Tees, Wear, Derwent, South Tyne and the East and West Allen
- These rivers have continued to rework the material deposited by the ice sheet during the last ice age
- The tributary rivers have cut steep valleys as they try to reach the main valley over-deepened by the ice sheet
- The rivers flow over dramatic waterfalls where they cross rocks of differing hardness especially at High Force

Slide 20 – Photograph of Teesdale and the River Tees at High Force

Slide 21 – Landscape processes on the North Pennines

Weathering

- Weathering has worked on the exposed rock faces and surfaces
- Boulder strewn slopes have been produced by freeze-thaw action
- Solution weathering has dissolved limestone to produce features of a karst landscape
- The karst landscape features include limestone pavements, cave systems and natural bridges

Slide 22 – Photographs of a limestone pavement and God's Bridge

Slide 23 – Human use of the North Pennines

- People have lived on the North Pennines for 10,000 years
- They have changed the landscape through farming, mining, quarrying, forestry and settlement
- Farming has gradually removed most of the woodland that once covered the North Pennines and replaced it with moorland, flower-rich meadows and grasslands
- The North Pennines was once Europe's most important area for lead production
- There is a long history of quarrying limestone, sandstone and dolerite in the North Pennines

Slide 24 – Photographs of hay meadows, smelt mill and a quarry in the Great Limestone