The Pennines and adjacent areas

This account provides a broad perspective of the geology of the Pennines and adjacent areas region, which includes Greater Manchester, Lancashire, Merseyside, South Yorkshire, West Yorkshire, and parts of Cheshire, Cumbria, Derbyshire, Lincolnshire, North Yorkshire, Nottinghamshire and Staffordshire. Figure 1 provides a geological sketch map of this region showing the rock types occurring in relation to the major towns and cities. This account outlines the geology to a depth of at least a kilometre and summarises the current and historical use of the geological resources in the area.

Geology influences many aspects of the varied countryside and land-use of this region. In fact, it is the underlying geology that gives so much of the distinctive character to stunning landscapes from the Lancashire fells to the Derbyshire Peak District. The exploration and exploitation of resources, including hydrocarbons and minerals, has resulted in a detailed knowledge of the geology of the region. Industrial developments that flank the southern part of the Pennine Hills are centred near accumulations of natural mineral resources including coal and limestone. Natural outcrops of rock, surface mines and quarries provide information on the geology near the surface, with underground mines giving detail at depth. Insight into geology below the level of mining comes from borehole investigations associated with water and hydrocarbons exploration, the latter also associated with techniques such as geophysical seismic surveys that provide an understanding of the deep geological structure of the region by sending sound waves through the ground.

Geologically recent surface deposits

The region has widespread geological deposits of relatively recent origin, formed over the past 2 to 3 million years and spanning the Ice Ages and Interglacial periods. These are known as superficial deposits and include clays, sands, gravels and peat deposits laid down by former ice-sheets, rivers and coastal processes. Although absent in some areas, these deposits are present at depths of up to 70 m beneath parts of Greater Manchester. They include stiff boulder clays, sand and gravel, and soft clay that are particularly common in lowland parts of North Yorkshire, north Cheshire and west Lancashire. Layers of peat also form lowland mires to the south and west of Manchester whilst a blanket of thin peat covers much of the moorland areas in the Pennines and Peak District. Most of the superficial deposits are soft and easily eroded, as they have not been deeply buried and consolidated to form strong rocks. The superficial deposits are not considered further in this account.
**Figure 1** Geological sketch map showing the range and distribution of different rock types in The Pennines and adjacent areas. The extent of the region is identified on the inset map of the United Kingdom.
Geology at depth

Below the geologically recent surface deposits, or with just a cover of soil where such deposits are absent, are older rocks which geologists broadly split into two distinct types:

- The **sedimentary bedrock geology** is composed of quite hard rocks which were deposited between about 360 to 200 million years ago as layers of sediments in shallow seas, deserts and swamps (in similar environments to the present-day Mississippi delta and Arabian Gulf) in times when Britain lay closer to the Equator and the climate and landscape were very different from those of today.

- The **basement geology**, which underlies the bedrock, is over 420 million years old and mainly comprises harder, denser rocks which have been strongly compacted and folded. They include both rocks originally deposited as sediments and others that are products of volcanic activity or formed from the solidification of molten rock below ancient volcanoes.

The Pennine region has been affected by several phases of earth movements that caused local uplift of the sedimentary rocks, resulting in removal by erosion (in some parts of Lancashire up to several thousand metres of rocks are thought to have been removed). These processes have allowed older rocks that were once deeply buried to be brought close to the surface. Figures 2 and 3 are vertical sections through the geology, referred to as geological cross-sections, which illustrate the variations in geology across the region.

![Figure 2 Schematic cross-section of the geology of The Pennines and adjacent areas from The Fylde to North Yorkshire. The alignment of the section and key are shown Figure 1.](image-url)
Pennines and adjacent areas v2

Figure 3 Schematic cross-section of the geology of The Pennines and adjacent areas from the Wirral to Nottinghamshire. The alignment of the section and key are shown in Figure 1.

The Pennine Hills run north-south and are composed of sedimentary bedrock with the overall structure of a dome or arch that geologists refer to as an anticline (Figure 2). Because of erosion the oldest layers are preserved north-south along the centre of the hills with the overlying sedimentary layers becoming younger to the east and west down the flanks.

The basement rocks are very rarely encountered at the surface (Figure 1), but are known to be present at depths of at least 1500 m beneath the remainder of the region. The basement geology has only been drilled by a few deep exploration boreholes for oil and gas. Much of the structure at this depth is interpreted from other techniques including seismic surveys and other geophysical surveys, carried out on land or by low flying aircraft, which reveal patterns of the Earth’s gravity and magnetic field.

A major potential hydrocarbon resource has recently been identified within some of the shale rocks (the Craven Group) present under parts of the region. Although commercial production is probably some years away, exploration is now underway in parts of Lancashire. Any production of gas from the shale layers by the process known as fracking is likely to take place over 1500 m below the surface.

Individual areas

There are three broad landscapes present within the Pennine region, each having a characteristic underlying geology. These are the moorlands of the Peak District and Pennine Hills in the central part of the region; flanked by the coalfields of industrial south Lancashire, west Yorkshire and Derbyshire; and the mainly rural adjacent lowland plains found in west Lancashire through to Cheshire and from the Vales of Richmond and York southwards to east Nottinghamshire. These distinct landscapes are used here as the basis with which to describe the geology.
Peak District and Pennine Hills

This area comprises the Pennines between Blackburn and Lancaster in the west, and Richmond, Leeds-Bradford in the east, and also incorporating, in the southern part, the Peak District extending to Derby (Figure 1). The rocks of this area have generally given rise to poor acidic soils that are not suitable for crops and have resulted in predominantly livestock-based farming.

Sedimentary Bedrock

In the Peak District and Pennine Hills, the bedrock is formed by sedimentary layers that can be divided between:

- an upper sandstone and mudstone unit (Figure 4), referred to as the Millstone Grit and an underlying mudstone unit and potential hydrocarbons resource, the Craven Group, that is present beneath much of the Pennine Hills, from north of Derby and Leek (Staffordshire), to Harrogate and Catterick (North Yorkshire) and south of Preston to Lancaster (Lancashire); and
- a lower limestone unit, commonly known as Carboniferous Limestone (Figure 5), that is present at surface in the Yorkshire Dales and Derbyshire Peak District.

![Millstone Grit exposed in the main cliff at Mam Tor, Derbyshire, with underlying mudstones present in the foreground.](image)

*Figure 4 Millstone Grit exposed in the main cliff at Mam Tor, Derbyshire, with underlying mudstones present in the foreground.*
In some places the layers are steeply tilted and folded, in response to ancient episodes of earth movements. Some of the sandstone and limestone layers within this bedrock are minor aquifers, meaning that they can provide minor amounts of water for local public supply.

Very thick accumulations of sediment within this area were deposited in deep basins in some parts of the area; in others uplifted areas of basement rocks occur, bounded by geological faults, leading to much thinner sediments. In parts of Lancashire and Yorkshire the Millstone Grit, Craven Group and Carboniferous Limestone are present to depths exceeding 2000 m below ground. Limestone is quarried extensively as a major source of aggregate and for cement manufacture. Historically, ores of lead, zinc and copper were deep-mined in parts of the Peak District, in the Forest of Bowland, and Wensleydale in North Yorkshire. Being soluble, the limestones have been dissolved by rainwater percolating through them to form many caves, dry valleys and sinking streams. Landscapes where drainage is underground through caves in this way are called karst landscapes. Such features are especially well developed in the Yorkshire Dales (Figure 5) and the White Peak. The limestones form an important aquifer locally, both for water flowing through caves and fissures, which are used for public supply but also for much deeper groundwater flow that feeds the famous springs at Buxton.

**Figure 5  Carboniferous Limestone at Gordale Scar near Malham, North Yorkshire.**
Basement rocks
The sedimentary bedrock layers rest on much older basement geology which, although only exposed at surface near Malham in North Yorkshire (Figure 1), has been proved by some deeper boreholes or interpreted from seismic surveys that were carried out for the exploration of oil and gas. Beneath most of the area, the basement comprises very old sedimentary rocks that are very hard, including slates, sandstones and mudstones and are intensely folded and faulted.

The basement rocks include a large intrusion of molten rock which cooled and solidified to form granite, some 60 by 25 km in extent beneath parts of Wensleydale in the Yorkshire Dales. This granite was indicated by regional gravity surveys and later proved at 500 m below ground surface by a deep borehole. The presence of a second granite beneath the southeastern parts of the Peak District has also been suggested from the gravity data, but this is so far unproven by drilling.

Coalfield areas
This area includes the two large coalfield areas that flank the Pennine Hills (Figure 1). The South Lancashire Coalfield in the west encompasses the predominantly industrial and urbanised tract of land between Liverpool (Merseyside), Burnley (Lancashire), and Manchester, and extends southwards to Macclesfield in Cheshire. The East Pennine Coalfield area runs from Leeds and Bradford in West Yorkshire, southwards past Sheffield (South Yorkshire) and Chesterfield (Derbyshire) to the western part of Nottinghamshire. A third small coalfield occurs near Ingleton.

Sedimentary Bedrock
The sedimentary bedrock of these areas contains coal resources and comprises a thick sequence of layers known as the Coal Measures, which rest on top of the slightly older sediment layers found at surface in the centre of the Pennines and the Peak District. These rocks formed in shallow and deep seas, with vast quantities being transported by large river deltas. Occasionally the tops of these deltas were exposed, which allowed massive swampy forests to develop. After burial the vegetation from these forests was compressed to produce thin layers of coal. The Coal Measures are locally present at depths exceeding 1500 m in south Lancashire between Liverpool and Manchester, and 1250 m to the south of Leeds in the East Pennine Coalfield. At Ingleton these rocks are only about 200 m thick.

The Coal Measures are formed by varied sedimentary rocks including grey coloured mudstone and sandstone, with individual layers rarely exceeding 50 m, and individual beds of coal typically up to 2 m thick. Some of the sandstone layers within these sequences are aquifers, providing minor amounts of water
for local public supply. In southern parts of the South Lancashire Coalfield, at Ingleton and in the eastern part of the East Pennine Coalfield, at depths of up to 350 m, these rocks are overlain by reddened rocks, known as the Warwickshire Group, in which limestones are also developed and the coal seams become rare. The gradation from grey, coal-bearing rocks to reddened rocks is due to change at the time they were laid down from tropical swamps and deltas, through to better drained areas where soils developed as the sediments became exposed to the air.

![An opencast clay working in the Coal Measures, South Yorkshire.](image)

**Figure 6** An opencast clay working in the Coal Measures, South Yorkshire.

The Coal Measures and Warwickshire Group have been extensively mined in the past for coal, iron (from iron rich layers called ironstones), fireclay (Figure 6), limestone (with various uses including as a flux in steelmaking) and sandstone for building purposes and as a crushed aggregate. The coal mining industry is now largely redundant having been in decline since the early 1900s, with deep mining having ceased at Ingleton in the 1930s and in south Lancashire in the 1990s. Only 3 deep mines are currently operational in the East Pennine Coalfield near Mansfield, Nottinghamshire, and between Doncaster and Leeds, from the thousands of mines that have been worked previously; the potential for further deep mining remains a remote possibility. Most deep coal mining operations have taken place at depths up to about 800 m below surface, with workings accessed by vertical shafts cut through the overlying rocks. Mining for coal has caused surface subsidence in some areas that have been undermined. Natural methane gas is produced from disused coal mines in numerous locations in the East Pennine Coalfield between Mansfield (Nottinghamshire) and Castleford (West Yorkshire).
Basement rocks are not encountered near the surface in the coalfield areas but occur at several kilometres depth over much of these areas.

**Lowland Plains**

This encompasses the two lowland areas in the western and eastern parts of the region separated by the Peak District - Pennine Hills and coalfields areas. The western area extends from Macclesfield and Manchester westwards to Chester and then northwards to include Liverpool (Merseyside) through Preston and Blackpool to Lancaster. The eastern part stretches from Catterick in the north, southwards through York to Doncaster (South Yorkshire) and then Newark and Nottingham (Figure 1).

**Sedimentary Bedrock**

A sequence of up to three sedimentary bedrock layers occurs in the Lowland Plains.

An uppermost mud-rich layer of sedimentary bedrock referred to as the Mercia Mudstone that was deposited in hot arid estuaries and coastal plains and is characteristically orange and red-coloured. The Mercia Mudstone is present in the northern part of Cheshire, parts of the Wirral and west Lancashire, and along the extreme southeastern part of the region in Nottinghamshire. The Mercia Mudstone is present at depths up to 1500 m in Cheshire, over 1000 m in west Lancashire and over 200 m in Nottinghamshire. To the west of the Pennines, thick beds of rock salt are developed beneath parts of north Cheshire and west Lancashire. These formed when the coastal plains, within which the Mercia Mudstone was laid down, dried out, allowing seawaters to become saturated with brine, from which the rock salt crystallised. These salt layers are up to 250 m thick, and have been mined in traditional ‘dry’ mines in parts of Cheshire near Northwich (at about 90 m depth), and in Lancashire near Blackpool (at 160 - 330 m depth). The salt has also been extracted as liquid brine by ‘solution mining’, a process where the mineral is dissolved underground and pumped to surface. The solution mined caverns are typically between 100 and 400 m below the surface. Specially designed and constructed solution-mined caverns are used for the storage of natural methane gas at depths between 300 and 730 m near Northwich in Cheshire.

The Mercia Mudstone is everywhere underlain by the Sherwood Sandstone (Figure 7). The orange and red coloured Sherwood Sandstone, which was deposited in mixed environments including large river systems and desert dunes, is present throughout the area and is the second most important aquifer in England. Water in this layer flows between the individual sand grains and within fractures in the rock and is generally low in natural minerals such as calcium carbonate making it suitable for agricultural or industrial use, and as drinking water. Where it occurs at depths greater than 500 m the water is commonly saline and so it is not
generally suitable for drinking water. Due to the prevailing tilt of the strata, the Sherwood Sandstone thins towards older rocks in the coalfield and moorland areas. The Sherwood Sandstone is present at depths from surface of up to 200 m in Nottinghamshire, 400 m in North Yorkshire, and over 1000 m in Cheshire. However, the boundary between these rocks and older rocks in much of Merseyside and Lancashire is a faulted one, meaning in those areas this bedrock is present at depths from surface of over 1000 m. Hydrocarbons have been produced from the Sherwood Sandstone at several localities within this region. Small gas and oil fields are present in west Lancashire and parts of Nottinghamshire and South Yorkshire. Once the hydrocarbons have been extracted from these fields in the future they become targets for the underground storage of natural methane gas or carbon dioxide. Methane gas is also produced in this region from abandoned coal mines in northern Cheshire and there may also be a coal bed methane resource beneath much of the East Midlands.

![Figure 7](image.png)

**Figure 7** Processing the Sherwood Sandstone into crushed rock aggregate, north Nottinghamshire.

Underlying the Sherwood Sandstone and occurring at surface on the eastern flank of the East Pennine Coalfield and Pennines is a layer of sediments up to 150 m thick that was deposited in deserts and shallow seas. The rocks include alternations of up to 50 m of limestones, mudstones and sandstones. This layer of bedrock thickens and tilts eastwards to reach a maximum depth of about 400 m beneath the easternmost parts of the region. Between Doncaster and Catterick, layers of up to 40 m of the mineral gypsum are present within these rocks, this was mined up until recently near Selby in North Yorkshire for use as a fertiliser and the main constituent of many forms of plaster. Subsidence hollows formed through the
dissolution of gypsum is a feature of the Ripon area (Figure 8). Some of the limestone layers in this area are aquifers, corresponding to the Magnesian Limestone found in Northern England and provide minor amounts of water for local public supply.

As with the coalfield areas, basement rocks are not encountered anywhere near the surface in the Lowland Plains, but do occur at several kilometres depth beneath these areas.

Figure 8  A subsidence collapse feature formed by natural dissolution of gypsum, near Ripon.