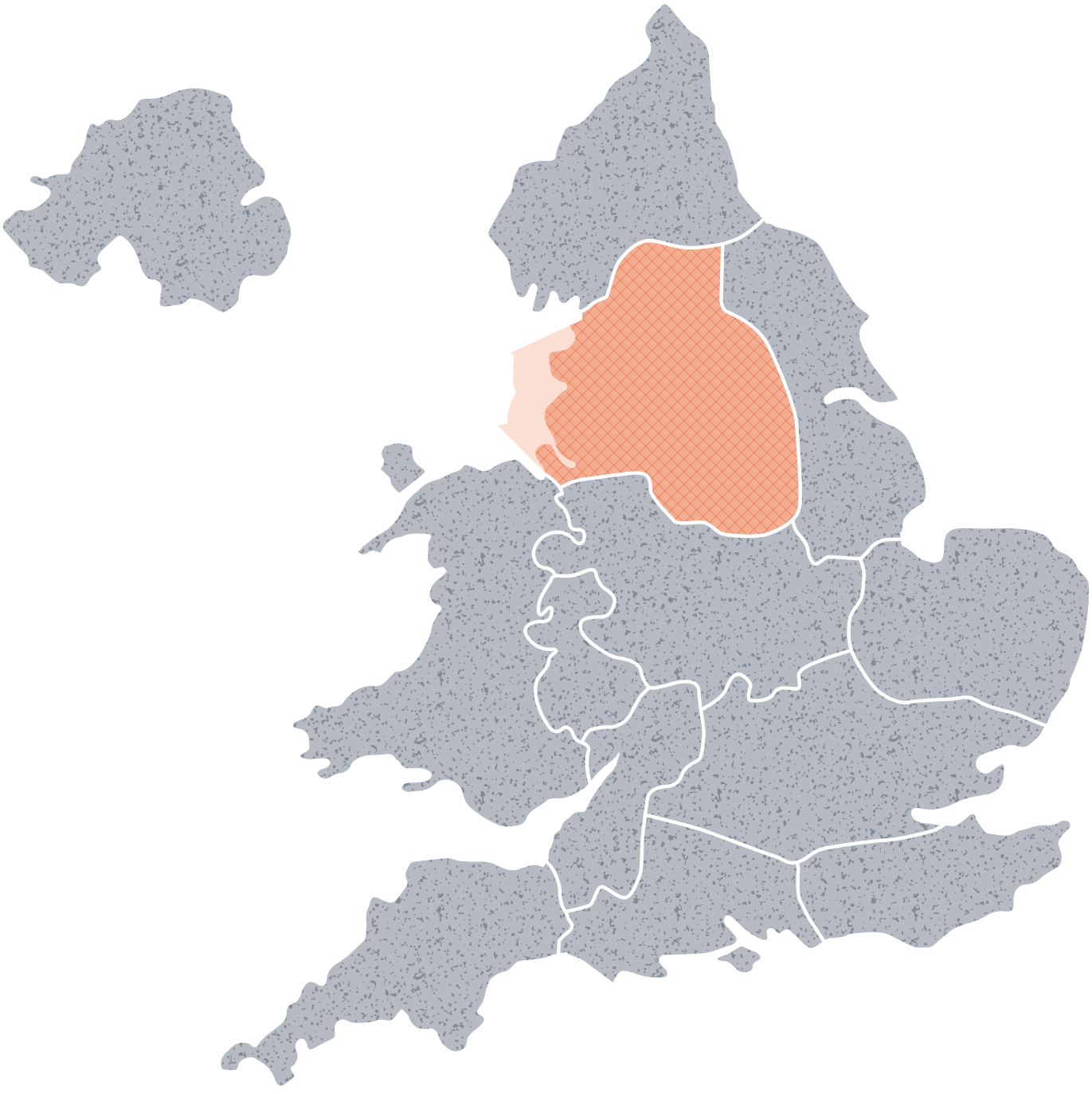
Radioactive Waste Management



# Pennines and adjacent areas

## REGIONAL GEOLOGY

# Contents



Clicking on words in green, such as sedimentary or lava will take the reader to a brief non-technical explanation of that word in the Glossary section. By clicking on the highlighted word in the Glossary, the reader will be taken back to the page they were on.

Clicking on words in blue, such as Higher Strength Rock or groundwater will take the reader to a brief talking head video or animation providing a non-technical explanation.

For the purposes of this work the BGS only used data which was publicly available at the end of February 2016. The one exception to this was the extent of Oil and Gas Authority licensing which was updated to include data to the end of June 2018.

## Introduction

This region comprises the Pennines from the Peak District to the Yorkshire Dales, covering parts of Yorkshire, Lancashire, Cheshire, Staffordshire, Derbyshire and Nottinghamshire and including the adjacent inshore area which extends to 20km from the coast.

## Subregions

To present the conclusions of our work in a concise and accessible way, we have divided the region into 4 subregions (see Figure 1 below). We have selected subregions with broadly similar geological attributes relevant to the safety of a GDF, although there is still considerable variability in each subregion. The boundaries between subregions may locally coincide with the extent of a particular Rock Type of Interest, or may correspond to discrete features such as faults. Although screening has focused on the 200 to 1,000m depth range, which is consistent with the Implementing Geological Disposal White Paper and National Geological Screening Guidance, we recognise that some rock types may be suitable as host rocks where they occur at depths greater than 1,000m.

## Pennines and adjacent areas: summary of the regional geology

What follows is a summary of the geology of the region, emphasising the geological attributes that are relevant to meeting the safety requirements for a GDF. Information about the geology of the region has been summarised by the British Geological Survey (BGS) in a Technical Information Report (TIR) on which this summary is based. This information comes from geological mapping, geophysical surveys and boreholes.

## Available information for this region

There are many boreholes extending below 200m in this region, most associated with the coalfields and the areas in the east and west of the region, that potentially contain reserves of oil and gas. Geophysical investigations include studies of the Earth's gravity and magnetic fields and recent detailed seismic surveys which have also been mainly undertaken in parts of the west and east of the region. There are a number of shallower boreholes that provide information on the groundwater above 200m, but very little information within and deeper than the depth range of interest for a GDF, 200 to 1,000m below NGS datum.

## Rock type

In order to describe the rocks present in the region we have divided them into 3 main groups: younger sedimentary rocks, older sedimentary rocks and basement rocks. These are summarised in Figure 2, which has been drawn up to show the oldest and deepest rocks at the bottom of the schematic rock column, with progressively younger rock units towards the top. Figure 3 is a geological map of the region showing where the major rock units occur at the surface. Figures 4a and 4b present schematic vertical cross-sections through the region. Within the 3 groups, individual rock units have been identified as Rock Types of Interest for the development of a GDF: Higher Strength Rock (HSR), Lower Strength Sedimentary Rock (LSSR) and Evaporite. Figures 5a to 5d show where in the region there are likely to be Rock Types of Interest within the depth range of interest.

### Younger sedimentary rocks

The youngest rocks occurring in the depth range of interest are sedimentary rocks of Triassic and Permian age (approx. 200 to 300 million years old), occurring in the west, south-west and east of the region. They are referred to here as the younger sedimentary rocks comprising sandstones, siltstones and mudstones which contain minor limestones and evaporite layers, including rock salt (halite), gypsum and anhydrite. There are several units in the younger sedimentary rock sequence which contain thick mudstones and are likely to behave as LSSR. These occur at the surface in the eastern and western parts of the region, and are encountered in boreholes both onshore and off the coast within the depth range of interest. They include potential LSSR and Evaporite host rocks present in the Mercia Mudstone Group and the Cumbria Coast Group in the west of the region and potential Evaporite host rocks present in the Zechstein Group in the area around Selby in the east.

### Older sedimentary rocks

The most common rocks in the region are Carboniferous sedimentary rocks (approx. 300 to 360 million years old) which were deposited directly on older basement rocks. They include the limestones of the Peak District and Yorkshire Dales, sandstones of the Millstone Grit sequence and the Coal Measures, dominated by coal, mudrock and sandstone. They occur within the depth range of interest largely in the centre and north of the region. Of these older sedimentary rocks, only the mudstones of the Warwickshire Group have potential as LSSR.

### Basement rocks

The oldest rocks of the region are of Silurian age or older (over approximately 420 million years old) and comprise mudrocks, sandstones and volcanic rocks locally intruded by granite. The mudrocks have been weakly metamorphosed to become slaty. They form the basement to the sedimentary rocks that rest on top of them. They are exposed at the surface in only a few places in the Yorkshire Dales, but are encountered also in deep boreholes across the region. Many of the same rock units occur at the surface in other regions, particularly Northern England. The granite has been sampled from only one borehole although its presence and general distribution is known from geophysical investigations. Some of these basement rocks are potential HSR host rocks.

### Rock structure

Major faults and areas of major folding are shown on the map in Figure 6. The younger sedimentary rocks are relatively unaffected by major faulting or folding. However some faults were active to the west of the Pennines during the time that these rocks were being deposited, so that the sedimentary units, including evaporites, become thicker to the west of the faults. Similar effects are seen in the older Carboniferous sedimentary cover rocks, with large changes in the thickness of some units across faults. Over much of the region, the basement rocks were intensely folded before any of the younger or older sedimentary rocks were deposited.

Faults occur on a diverse range of scales, from centimetres to kilometres, and the subsurface is criss-crossed by networks of numerous individual faults. However our work includes only those faults identified by the BGS with throws (vertical offset) of 200m or more. This is because the data available to the BGS are not able to resolve all faults consistently, across all thirteen regions, with throws less than 200m.

## Groundwater

There is very little information on groundwater in the depth range of interest for a GDF, 200 to 1,000m below NGS datum, although there is information on groundwater in aquifers above 200m. There are several principal aquifers within 400m of the surface in this region including the Sherwood Sandstone Group and the Carboniferous Limestone aquifer. Groundwater contained in these aquifers is likely to be separated from the groundwater in other aquifers and rocks at greater depth where low permeability LSSR layers are present between them, even where they are not thick enough to host a GDF.

Water moves through the aquifers towards the coasts on both sides of the Pennines, but where the sandstones are deeper and overlain by mudstones, water is likely to move more slowly; these deeper layers may contain brackish or saline water as they experience much less direct recharge from the surface. Similarly, the deeply-buried Carboniferous Limestone aquifer in the east of the region contains very saline brines that are interpreted as original Carboniferous (approx. 300 to 360 million years old) formation waters which were contained in these sediments when they were deposited. Groundwater from depths greater than 400m is unlikely to be suitable as drinking water anywhere in the UK[1].

There are natural thermal springs providing evidence for local deep circulation of groundwater through limestone and rapid flow back to the surface in the south of the region (Peak District) (Figure 7a). Mining is likely to have changed the original patterns of water movement in the central and eastern parts of the region and shallower groundwater may now circulate to greater depths within the depth range of interest than it did before mining.

## Resources

A wide range of resources have been exploited in this region. Areas with metal and vein mineral mines present below 100m are shown in Figure 7a. Areas with coal mines present below 100m are shown in Figure 7b. Areas with hydrocarbon fields are shown in Figure 7c. Areas of historic lead, zinc, barite and fluorite mining shallower than 100m and evaporite mines present below 100m are shown in Figure 7d.

The region has major coalfields on each side of the Pennines, with mine workings extending to depths of several hundred metres and there are also Coal Authority Licence Areas around Blackburn, Doncaster and in the inshore area off Liverpool (Figure 7b).

Petroleum Exploration and Development Licences[2] for conventional and unconventional hydrocarbons have also been granted on both sides of the Pennines, with oil mainly in the south-east and gas in the west (Figure 7c).

Parts of the south and west of the region have been an important source of salt, mainly extracted by solution mining, and salt caverns have potential future use for gas storage.

The areas where concentrations of deep exploration boreholes would need to be considered in the siting of a GDF are shown in Figure 8.

[1] Water Framework Directive UK TAG. Defining and reporting on groundwater bodies, 2012.
[2] This also includes other licences awarded by the Oil and Gas Authority to allow companies to explore for hydrocarbons.

## Natural processes

The UK has low levels of earthquake activity and correspondingly low seismic hazard. Earthquakes are seldom large enough to be felt and the ground surface is not known to have been broken by active faults. This region experiences small earthquakes with a similar frequency to other parts of England and Wales, and there are no particular locations where they are obviously more frequent. Only 12 earthquakes with magnitude of 4.0Mw or greater have been recorded in the past 500 years. The largest modern earthquake in the region was the magnitude 4.5Mw Skipton earthquake of 1944, which caused minor damage in the town; a slightly larger earthquake occurred in 1575 in the south of the region.

Whilst the design of a GDF will need to consider the potential impact of future earthquakes, there is no evidence that future seismicity anywhere in the UK would preclude its development.

The region was affected by continental-scale glaciation during the Pleistocene epoch, with the last major UK glaciation, known as the Devensian, leading to at least half of the region being covered by ice, with permafrost extending throughout the region. The earlier, Anglian, ice sheet covered the entire region. The precise siting and design of a GDF would need to consider the potential impacts of glaciation and permafrost during future continental-scale glaciations. These may include increased erosion and changes to groundwater movement.

The coastal area in the west of the region is susceptible to future groundwater changes in response to sea level change. The precise siting and design of a GDF would therefore consider the potential impacts of future sea level change.

## Further information

More information about the geology of the region can be found in the BGS Regional Summary, with additional detail in the BGS Regional Guide. This guide also provides details about many of the sources of information underpinning the TIR.

**Figure 1** Subregions of the Pennines and adjacent areas region as defined for the purpose of National Geological Screening.

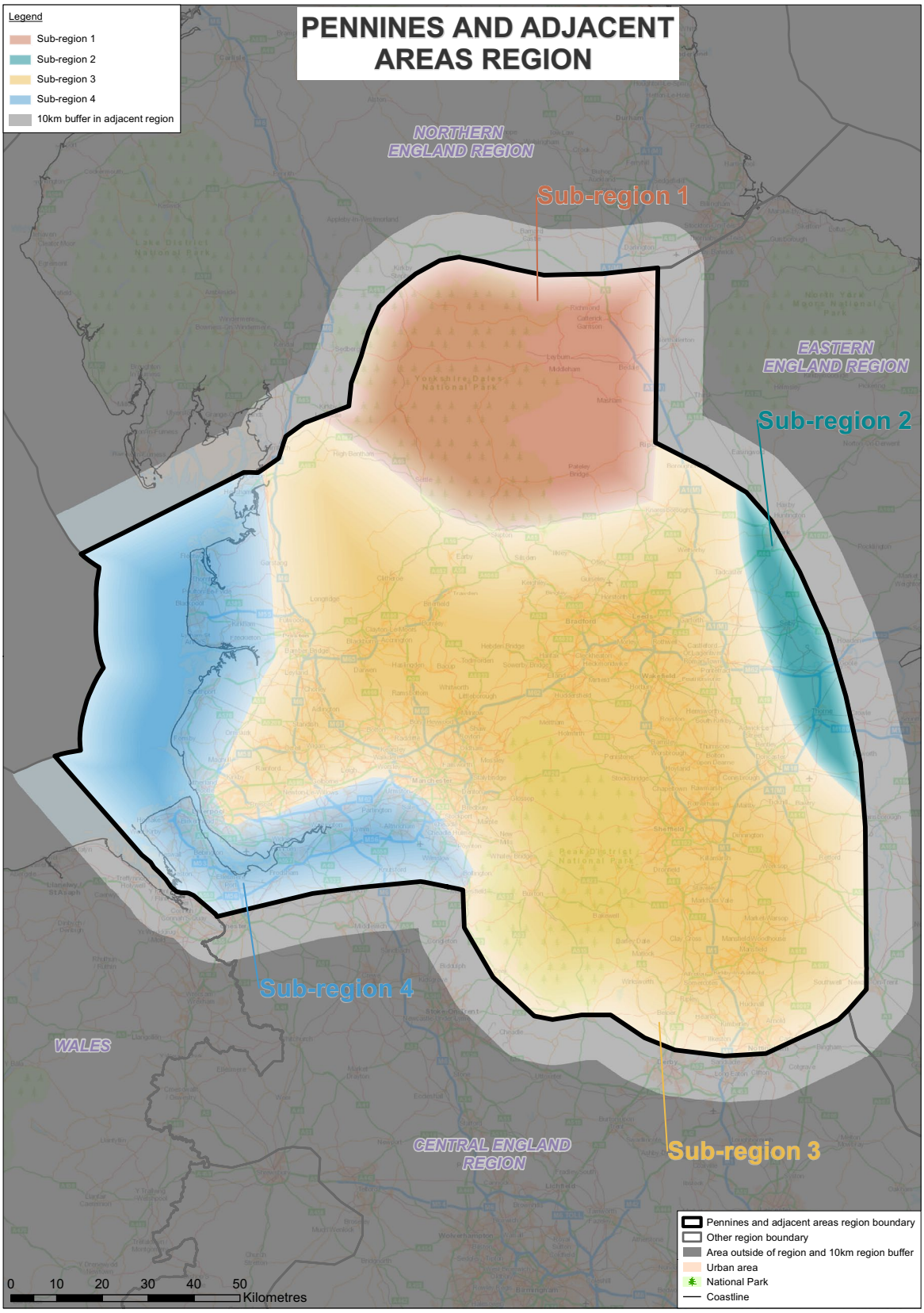
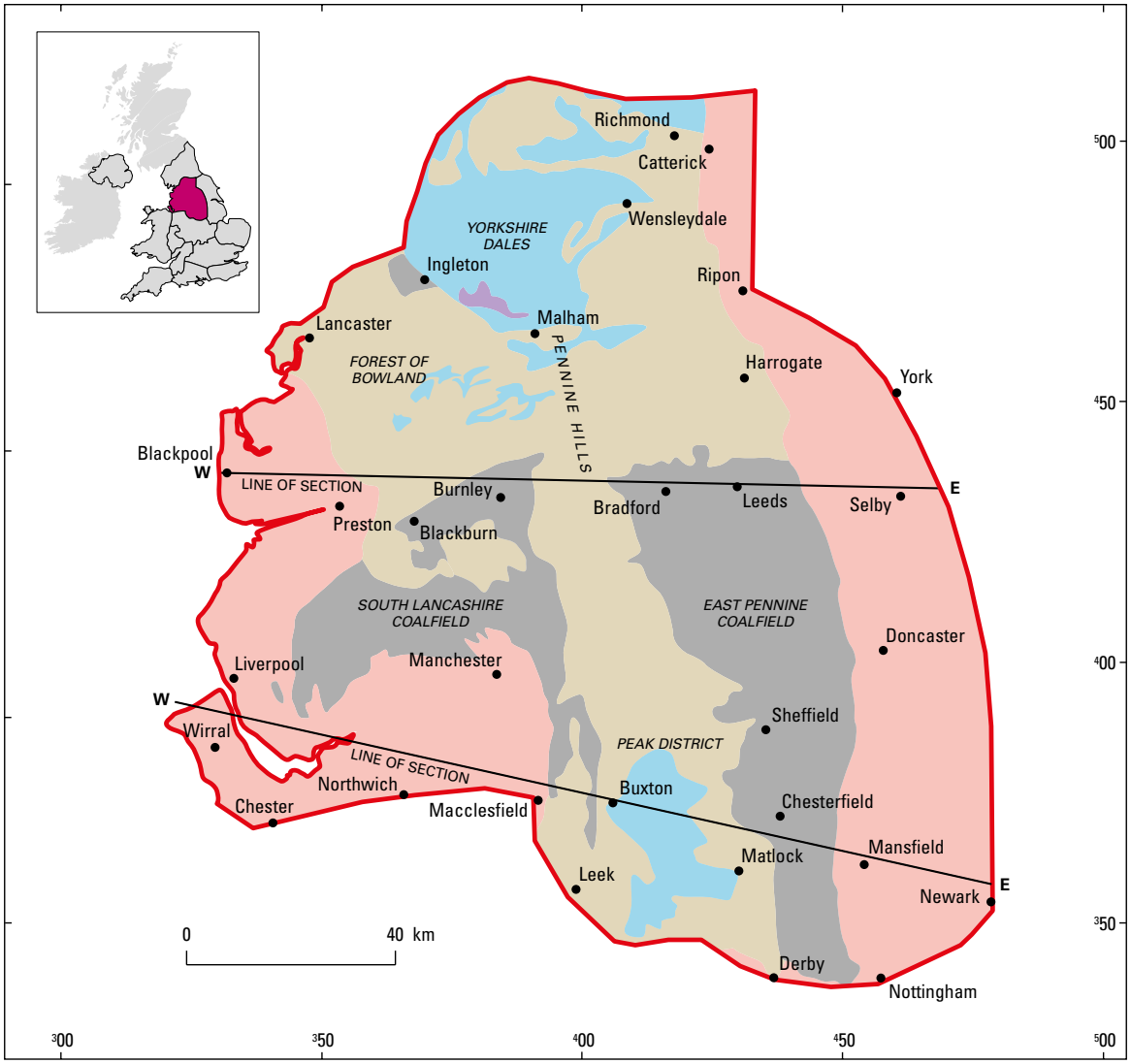


**Figure 2** Table illustrating the sequence of the major rock units present in the Pennines and adjacent areas region and their possible significance for the siting of a GDF[3].

| | Geological Period (age in millions of years) | Geological Unit | Dominant Lithology | Rock types of interest | | |
|---|---|---|---|---|---|---|
| | | | | LSSR | HSR | Evaporite |
| Younger sedimentary rocks | Triassic (201.3 – 251.9) | Mercia Mudstone Group | mudstone with siltstone and evaporite (anhydrite, gypsum and rock salt) | ✓ | | ✓ |
| | | Sherwood Sandstone Group | sandstone with conglomerate | | | |
| | Permian (251.9 – 298.9) | Cumbrian Coast Group (west) or Zechstein Group (east) | mudstone, siltstone and sandstone with evaporite (including rock salt) | ✓ | | ✓ |
| | | Appleby Group (west) or Rotliegendes Group (east) | sandstone, breccia and conglomerate | | | |
| Older sedimentary rocks | Carboniferous (298.9 – 358.9) | Warwickshire Group | siltstone and sandstone with subordinate mudstone and coal | ✓ | | |
| | | Pennine Coal Measures Group | mudstone, siltstone, sandstone and coal | | | |
| | | Millstone Grit Group | sandstone, siltstone and mudstone | | | |
| | | Craven Group | mudstone with sandstone and limestone | | | |
| | | Carboniferous Limestone Supergroup | limestones with mudstones | | | |
| Basement | Silurian (419.2 – 443.8) | Windermere Supergroup | mudstone, limestone and sandstone | | ✓ | |
| | Ordovician (443.8 – 485.4) | Wensleydale Granite | granite | | ✓ | |
| | | Ingleton Group | weakly metamorphosed slates and sandstones | | ✓ | |

[3] Gaps in time in this column with no rock types shown either represent periods when no rocks were being formed or indicate that the rocks formed during these periods have subsequently been removed by erosion.

**Figure 3** Generalised geological map showing the distribution of rock units in the Pennines and adjacent areas region. The inset shows the extent of the region in the UK. The bold black lines give the locations of the cross-sections shown in Figures 4a and 4b. See Figure 2 for the key to the rock types shown.




It should be noted that the area covered by this map is slightly different to the area considered in this document. This is because, unlike the region considered in this study, it refers to the BGS Regional Guide area which does not strictly follow the national boundary of Wales.

**Figure 4a** Schematic east to west cross-section to show the structure of the major rock groups across the Pennines and adjacent areas region from The Fylde to North Yorkshire. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

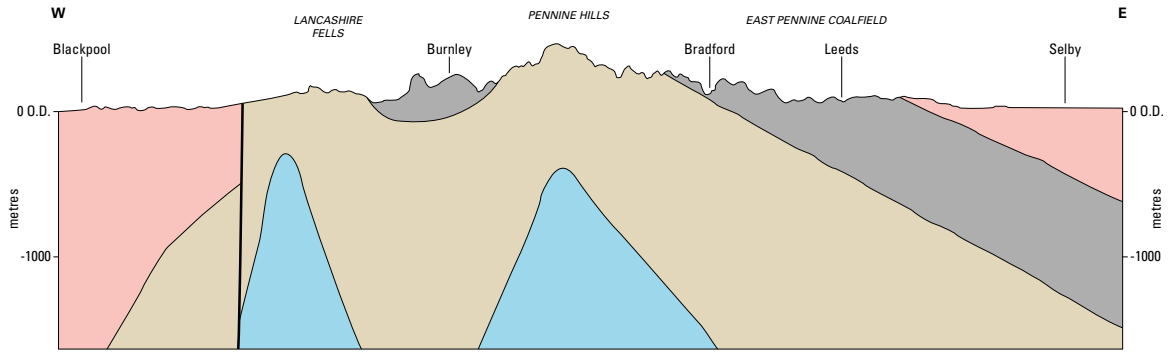



**Figure 4b** Schematic east to west cross-section across the Pennines and adjacent areas region from the Mersey estuary through the Peak District to Newark. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

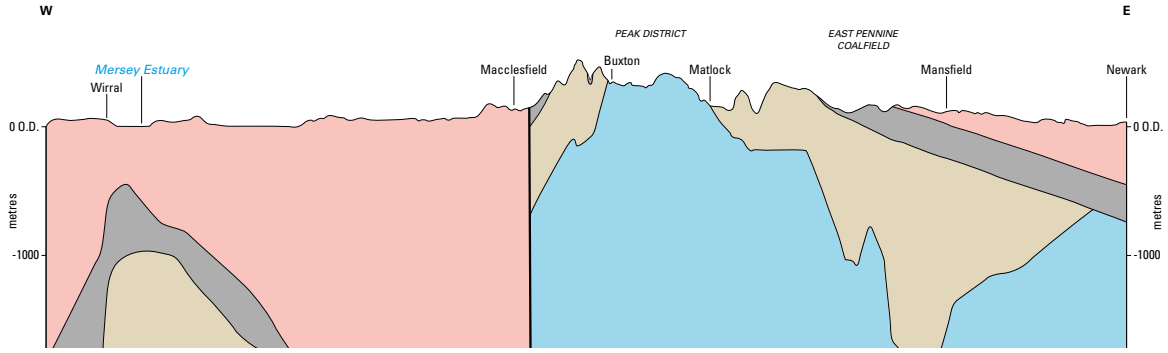


**Figure 5a** The areas of the Pennines and adjacent areas region where any of the 3 Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

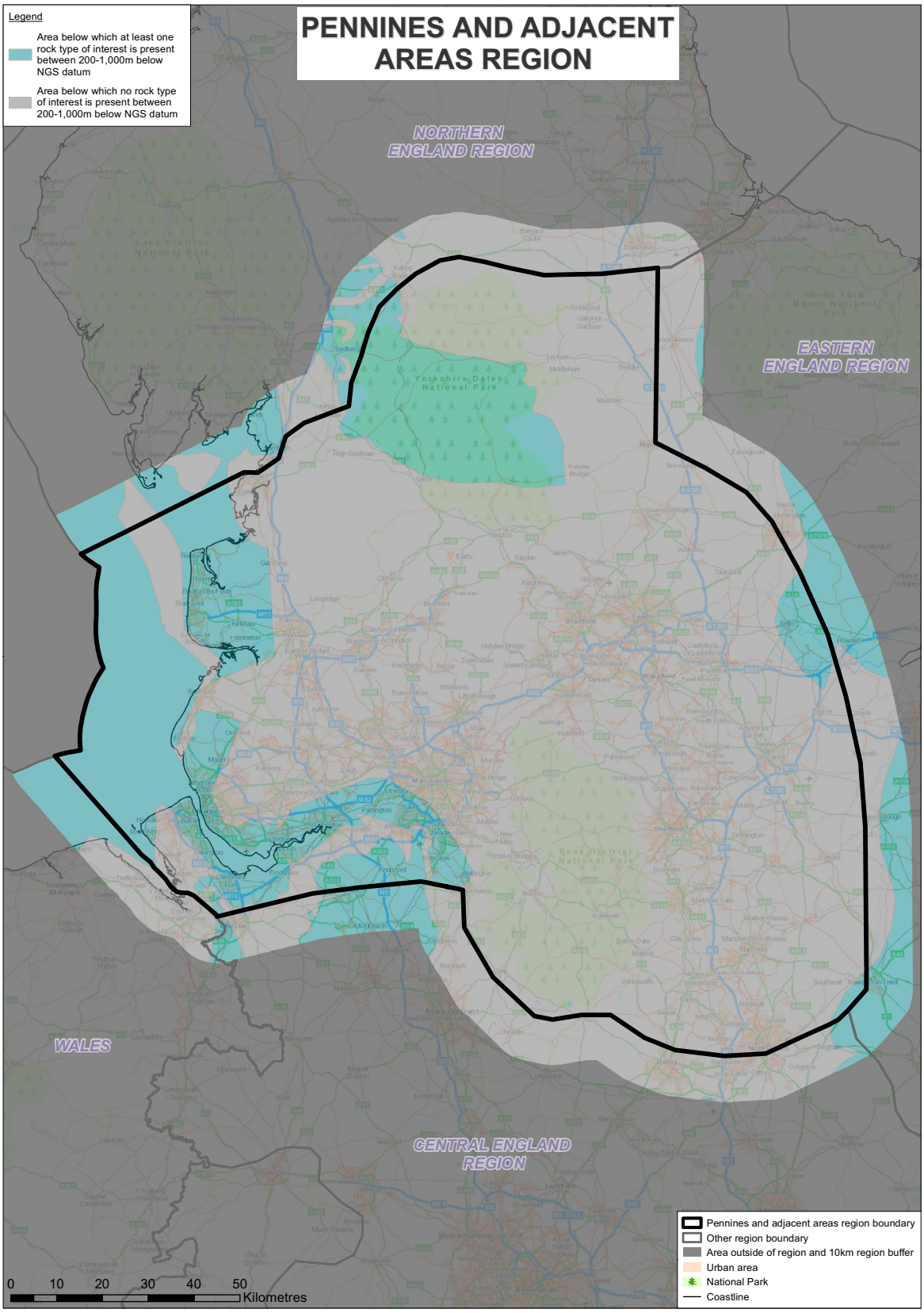


**Figure 5b** The areas of the Pennines and adjacent areas region where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

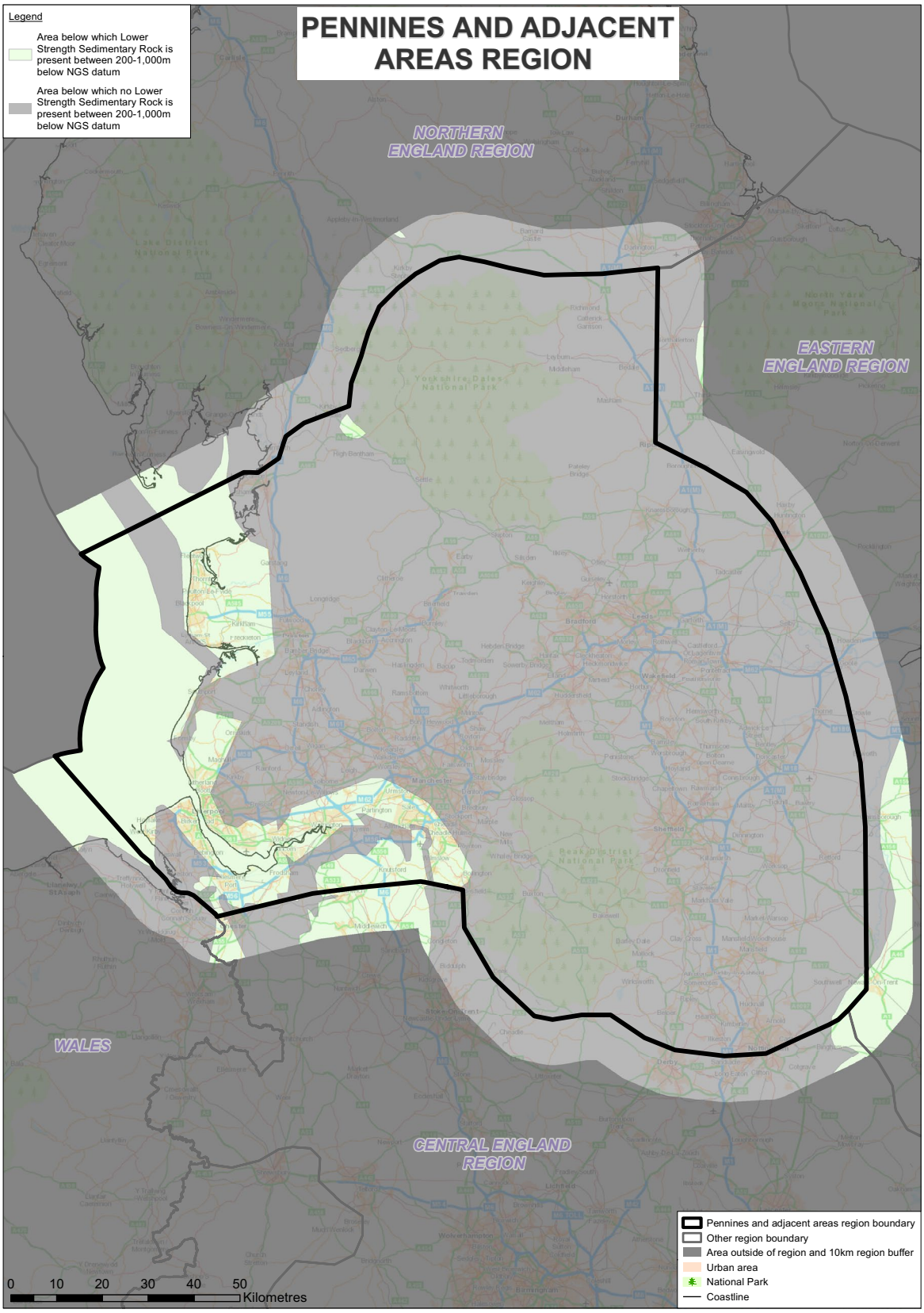


**Figure 5c** The areas of the Pennines and adjacent areas region where Higher Strength Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

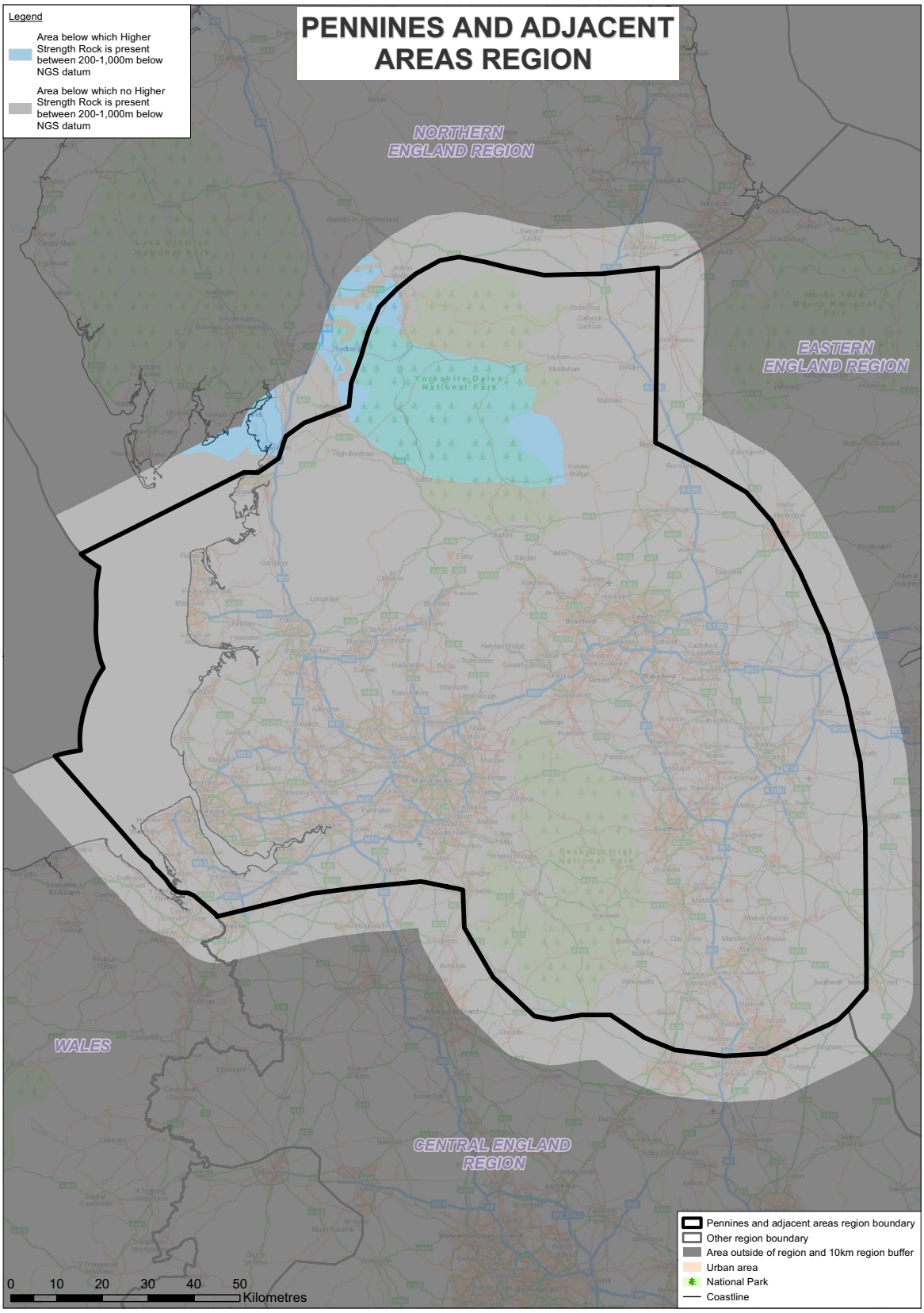


**Figure 5d** The areas of the Pennines and adjacent areas region where Evaporite Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

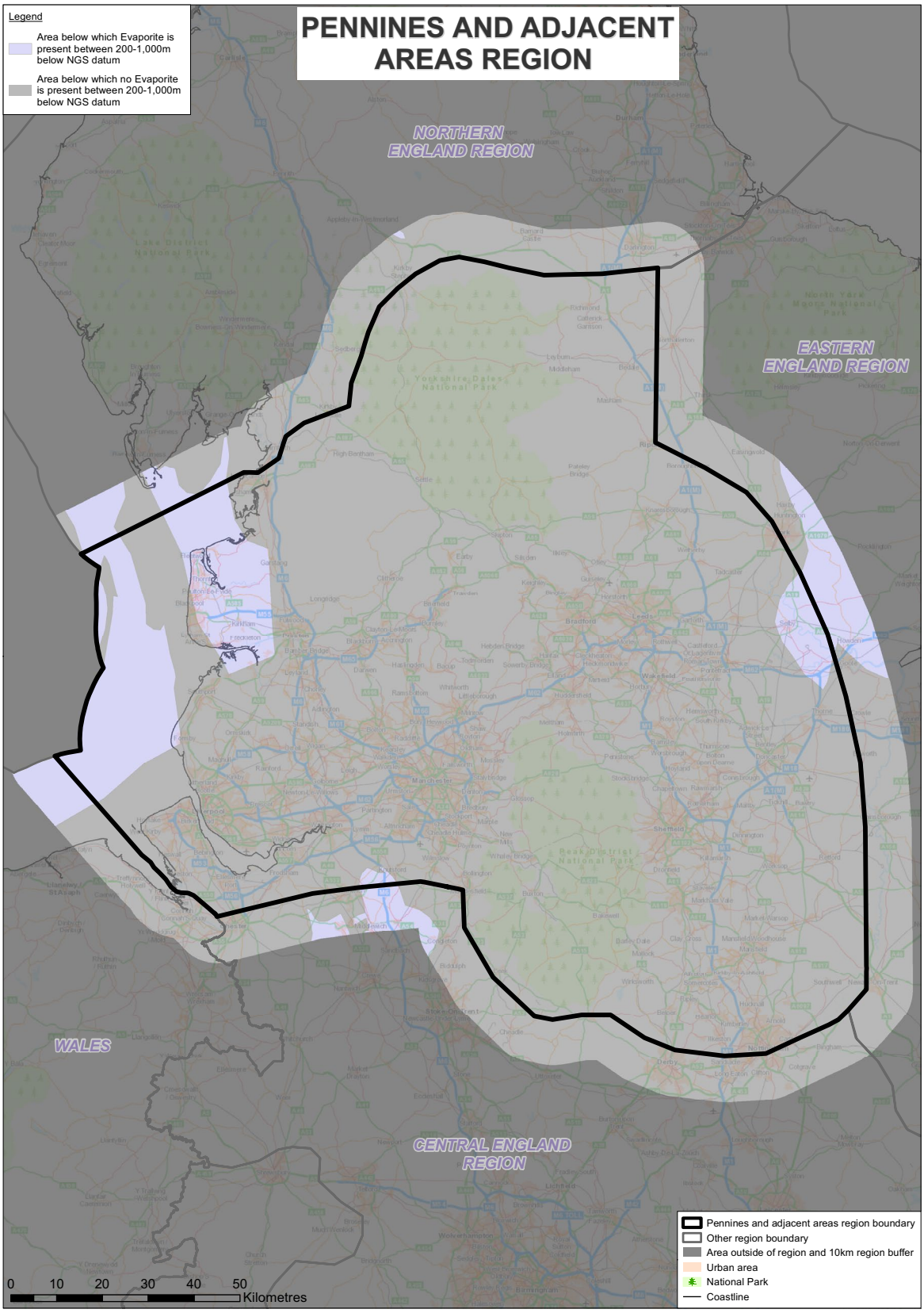


**Figure 6** Location of major faults in the Pennines and adjacent areas region.

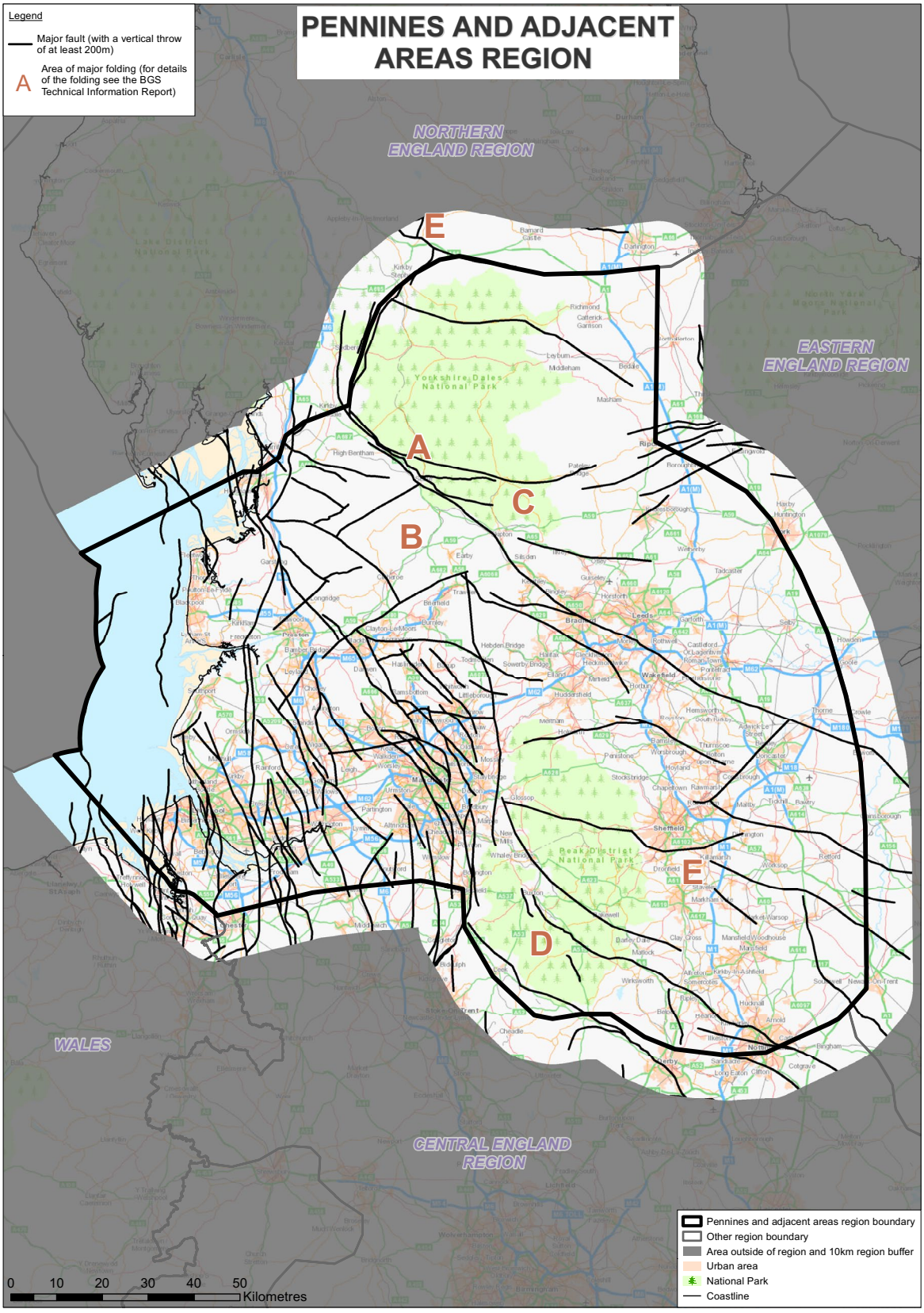


**Figure 7a** Areas of the Pennines and adjacent areas region with thermal springs and metal and vein mineral mines present below 100m.

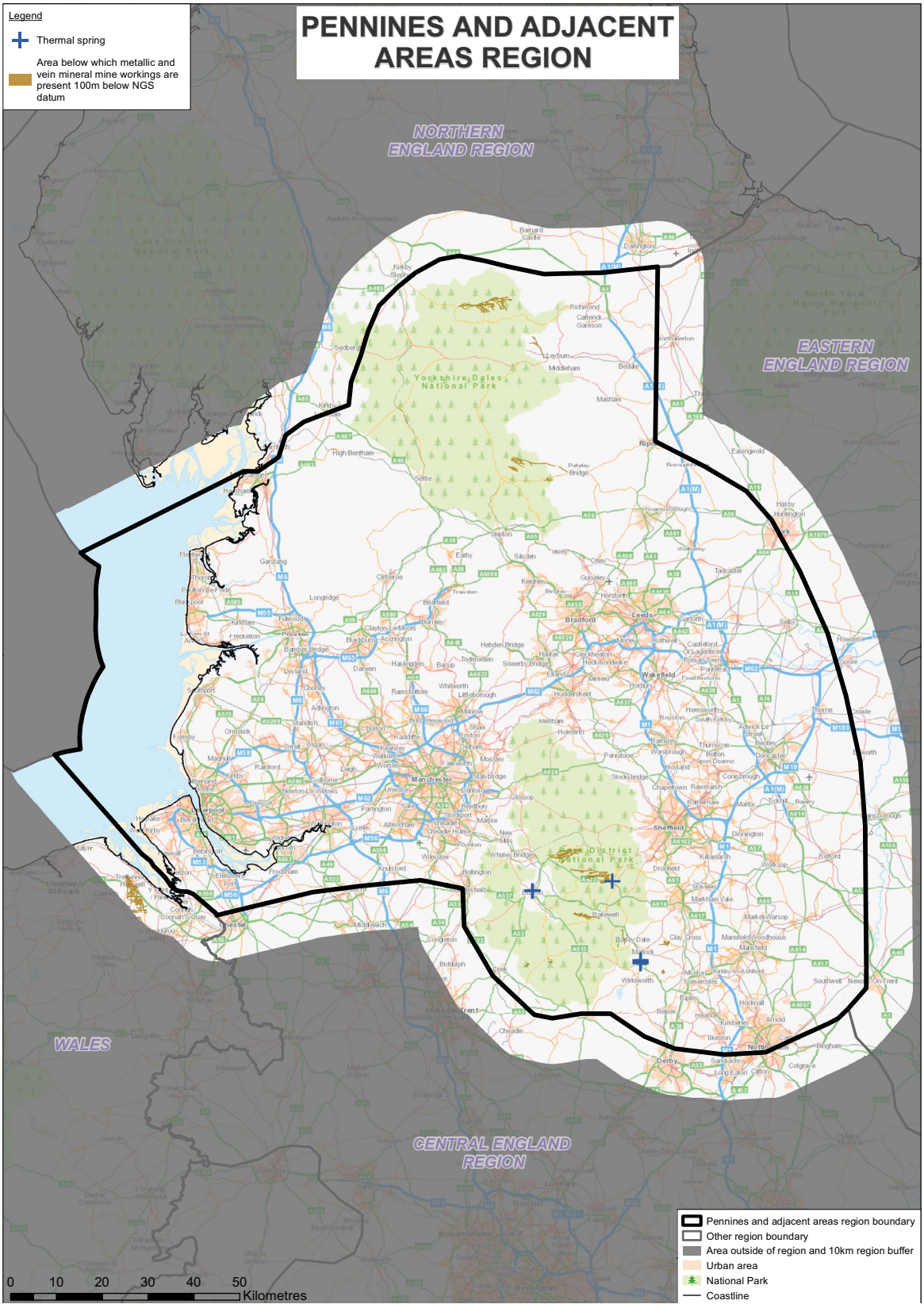


**Figure 7b** Areas of the Pennines and adjacent areas region with coal mines more than 100m deep and Coal Authority Licence Areas.

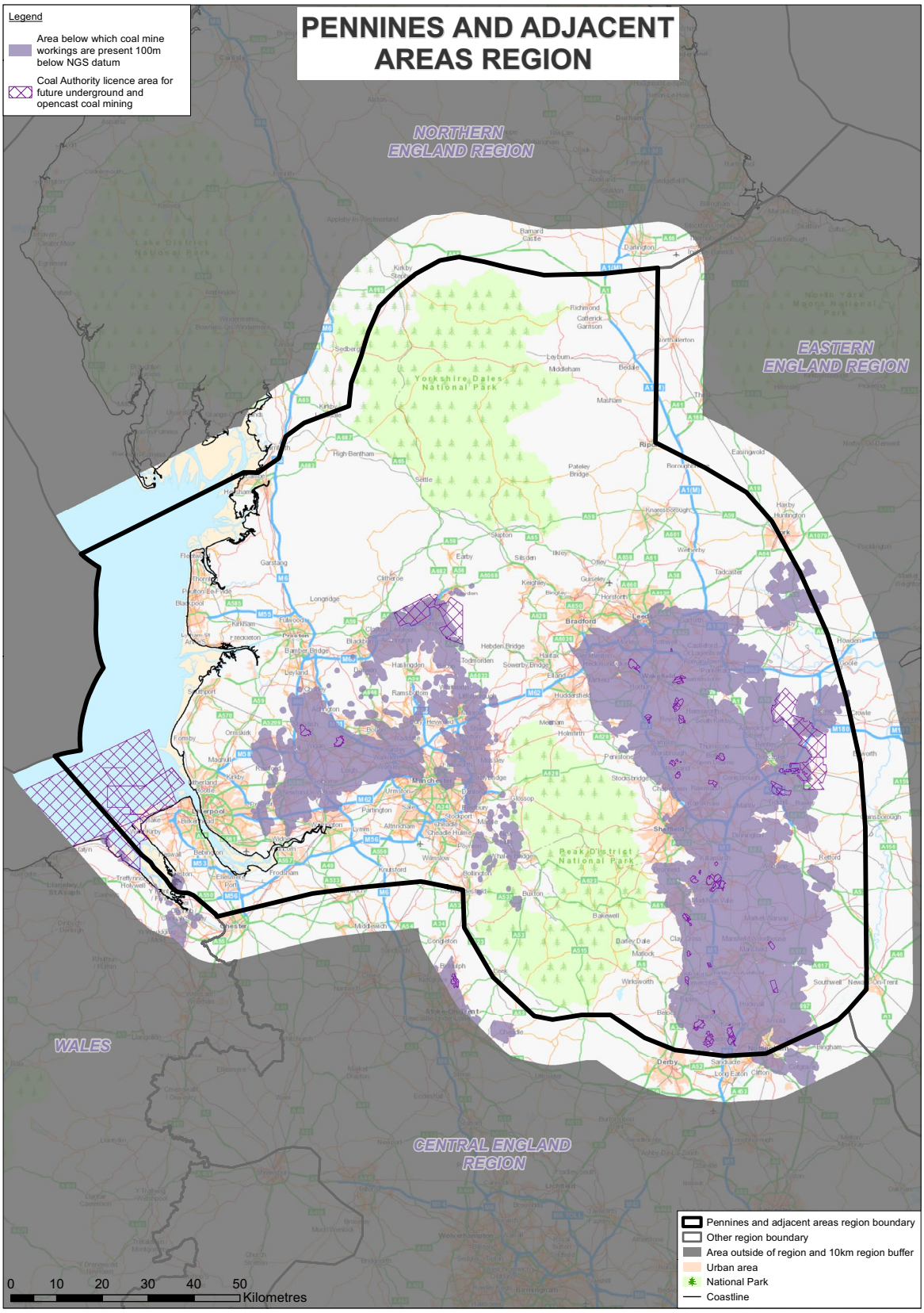


**Figure 7c** Areas of the Pennines and adjacent areas region with oil and gas fields and Petroleum Exploration and Development Licences.

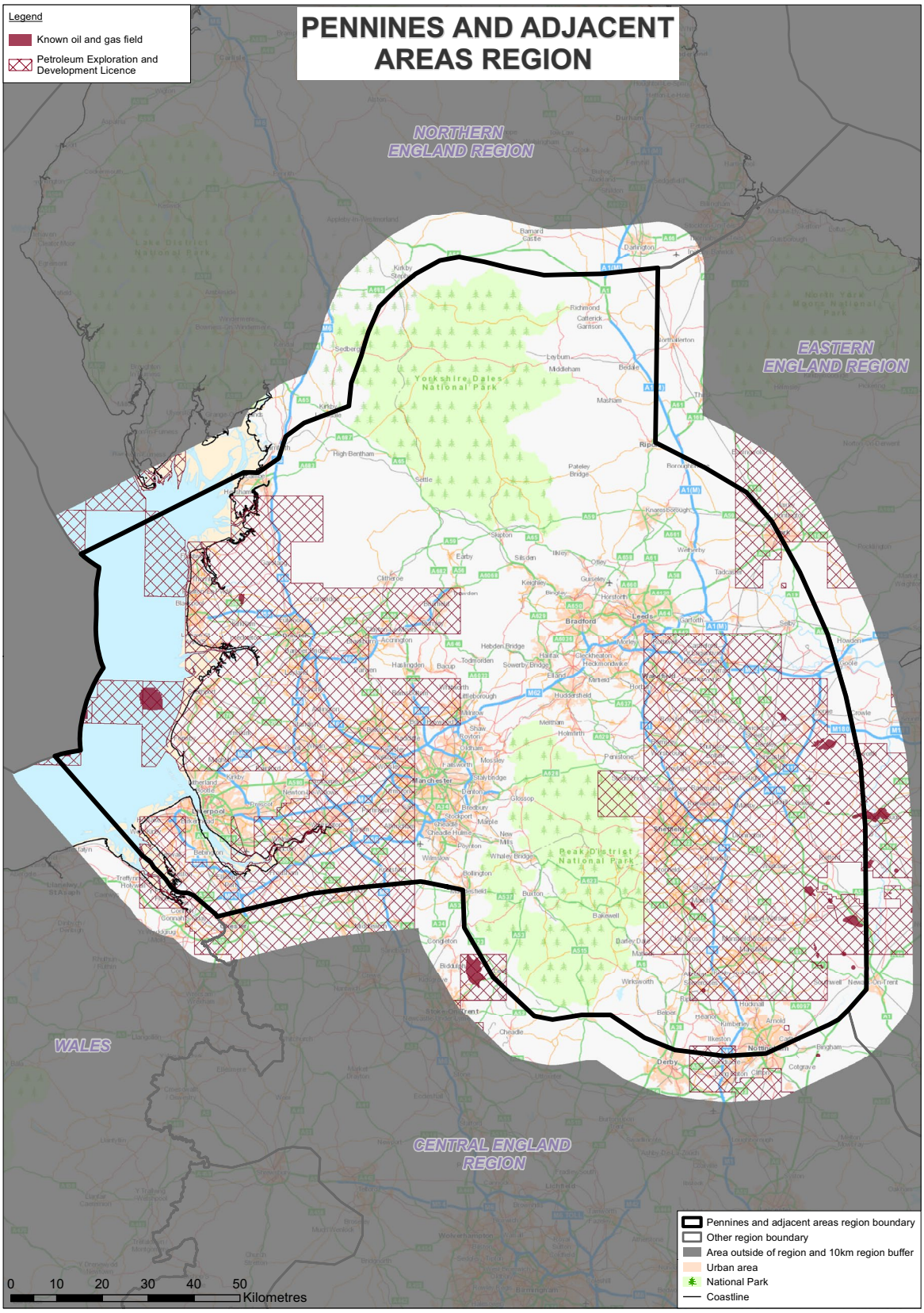


**Figure 7d** reas of the Pennines and adjacent areas region with historical mines less than 100m deep, known mineral prospects and evaporite mines present below 100m.

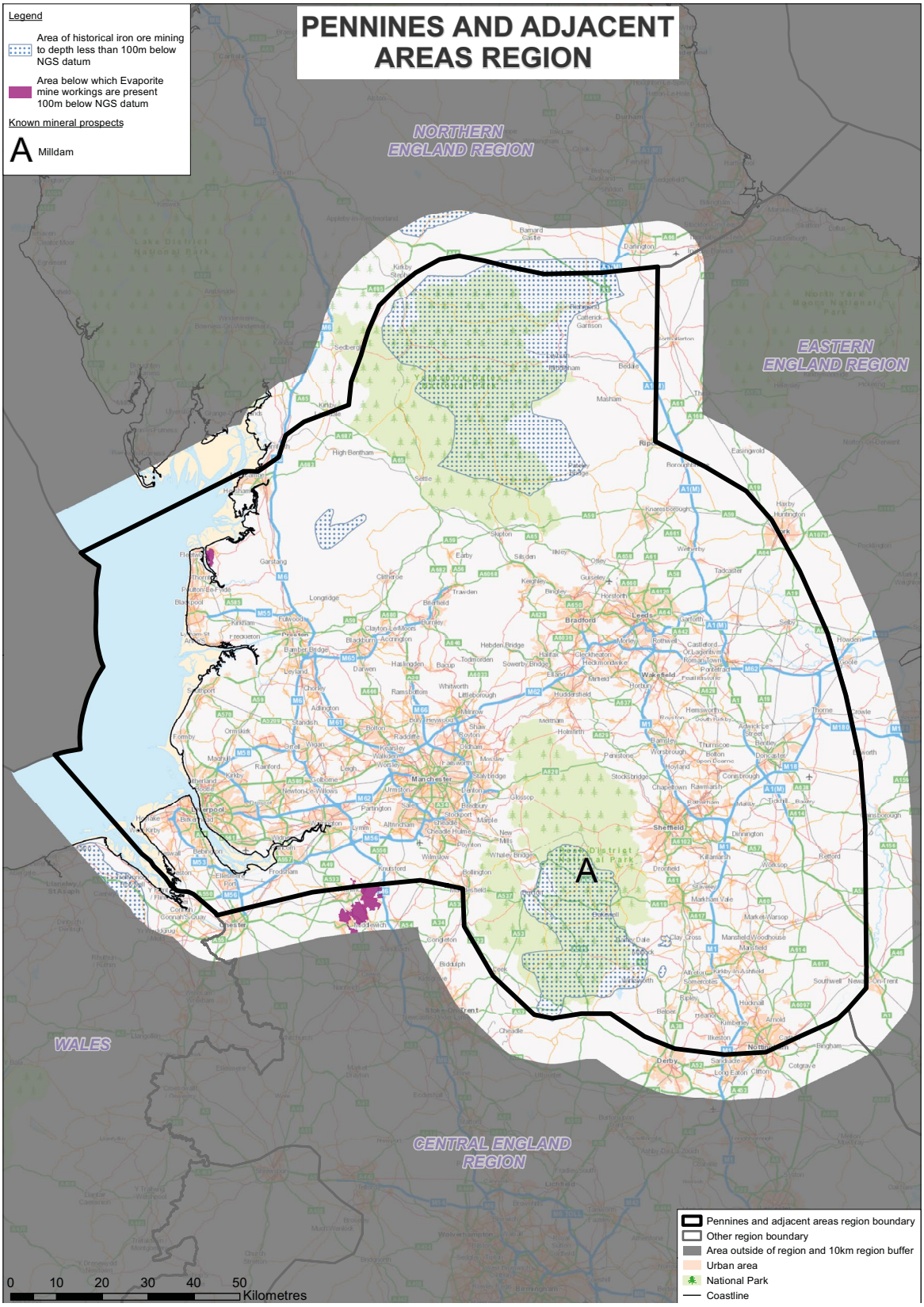
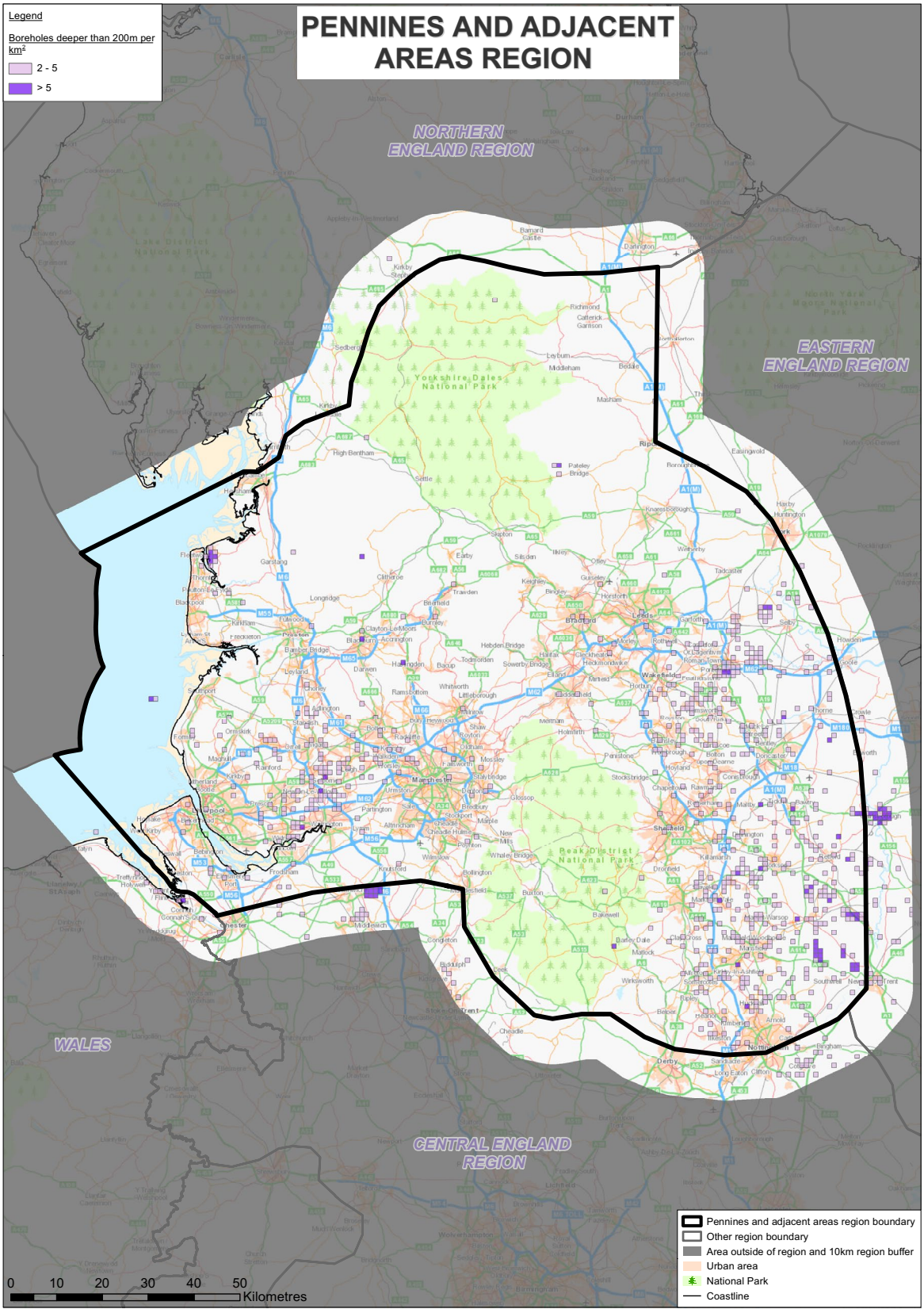


**Figure 8** Areas in the Pennines and adjacent areas region with concentrations of deep exploration boreholes.



# Glossary

### Active faults
A fault that has moved once or more in the last 10,000 years and is likely to become the source of an earthquake at some time in the future.

### Anglian
A glaciation event during the last ice age about 450,000 years ago, where ice sheets extended as far south as the Severn and Thames Estuaries.

### Anhydrite
A calcium sulphate mineral that forms from the evaporation of salty seas. It contains no water and occurs at greater depths and higher temperatures than gypsum.

### Aquifers
Aquifers are rocks that contain freshwater in pores and/or fractures and whose porosity and permeability are sufficiently high to make the extraction of groundwater possible.

### Brackish
Water that is more salty than freshwater, but does not contain as much dissolved salt as seawater.

### Conventional hydrocarbon
Underground petroleum products (i.e. oil & gas), trapped in high-permeability reservoir rocks, that are extracted using well-established methods that are commonplace in the oil, gas and mining industries.

### Devensian
The most recent glacial period, popularly known as the last Ice Age, which occurred from c.110,000 to 12,000 years ago.

### Dip
The angle, or slope of a plane, such as sedimentary layering, measured relative to the horizontal.

### Erosion
The process by which the land surface is worn down, mainly by the action of rain, rivers, ice and wind leading to removal of huge volumes of soil and rock particles.

### Evaporite
The generic term for rock created by the evaporation of water from a salt-bearing solution, such as seawater, to form a solid crystalline structure. Gypsum, anhydrite and halite are all types of evaporite.

### Fault
A fracture in the earth's crust across which the rock layers each side of it have been offset relative to one another.

### Formation waters
Water that occurs naturally in the pores of a porous rock, sometimes this water is the same water that was trapped when the rocks were deposited. These ancient trapped waters are sometimes called fossil water.

### Granites
Pale-coloured, coarse crystalline igneous rock rich in silica, sodium, calcium and potassium.

### Gypsum
A calcium sulphate mineral that forms from the evaporation of salty seas. It contains water and occurs at shallower depths and lower temperatures than anhydrite.

### Halite
A sodium chloride evaporite mineral that forms when salty water dissolves. Also known as rock salt, or just 'salt'.

### Hydrocarbon
A compound of hydrogen and carbon. Hydrocarbons are the chief components of oil and natural gas.

### Lithology
The physical properties of rock types.

### Metamorphosed
A rock that has undergone change due to the action of temperature and pressure.

### Pleistocene
The Pleistocene describes the period of geological time between c.2.5 million years ago and 11,700 years ago. It represents the time period spanning the world's most recent period of repeated glaciations. This period is sometimes referred to as "the Ice Age" however, "ice age" can refer to several periods throughout geological history.

### Principal aquifers
An aquifer classified by the Environment Agency as: "rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage." They represent the most important aquifers in terms of water supply or base flow.

### Saline
Containing salt (e.g. seawater is saline).

### Sedimentary
A type of rock resulting from the consolidation of material that has accumulated in layers to form gravel, sandstone, mudstone and limestone. The layers may be built up by movement from erosion (e.g. by rivers, the sea or wind) or by chemical precipitation. Generally, the material that accumulates has originated from the weathering of other rocks. Sedimentary rocks constitute one of the three main classes of rocks identified by geologists, the others being igneous and metamorphic.

### Sediments
Solid fragmented material, such as silt, sand, gravel and other material (including chemical precipitates, like salt), deposited in rivers, lakes, seas and oceans. Generally, the material that accumulates has originated from the weathering of other rocks. This material is often transported by erosion and deposited in layers. Sediments form the building blocks of sedimentary rocks (see below).

### Seismic
Shaking in the earth's crust due to natural earthquakes.

### Slaty
Distinctive way in which slate rocks split into very fine sheets.

### Solution mining
A technique to extract soluble minerals out of the ground by pumping liquids into a deposit, dissolving the target minerals, returning the water to surface and reprecipitating the mineral. Solution mining for rock salt is carried out in the UK and for other commercially valuable minerals around the world.

### Unconventional hydrocarbon
Hydrocarbons (i.e. oil and gas) that are extracted from very low-permeability reservoirs from which the hydrocarbons can only be unlocked by fracking.

### Vein
Sheet-like accumulations of minerals that have been intruded into fractured rock. Commonly they are made up of quartz or calcite crystals but can also contain small concentrations of precious metals.

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