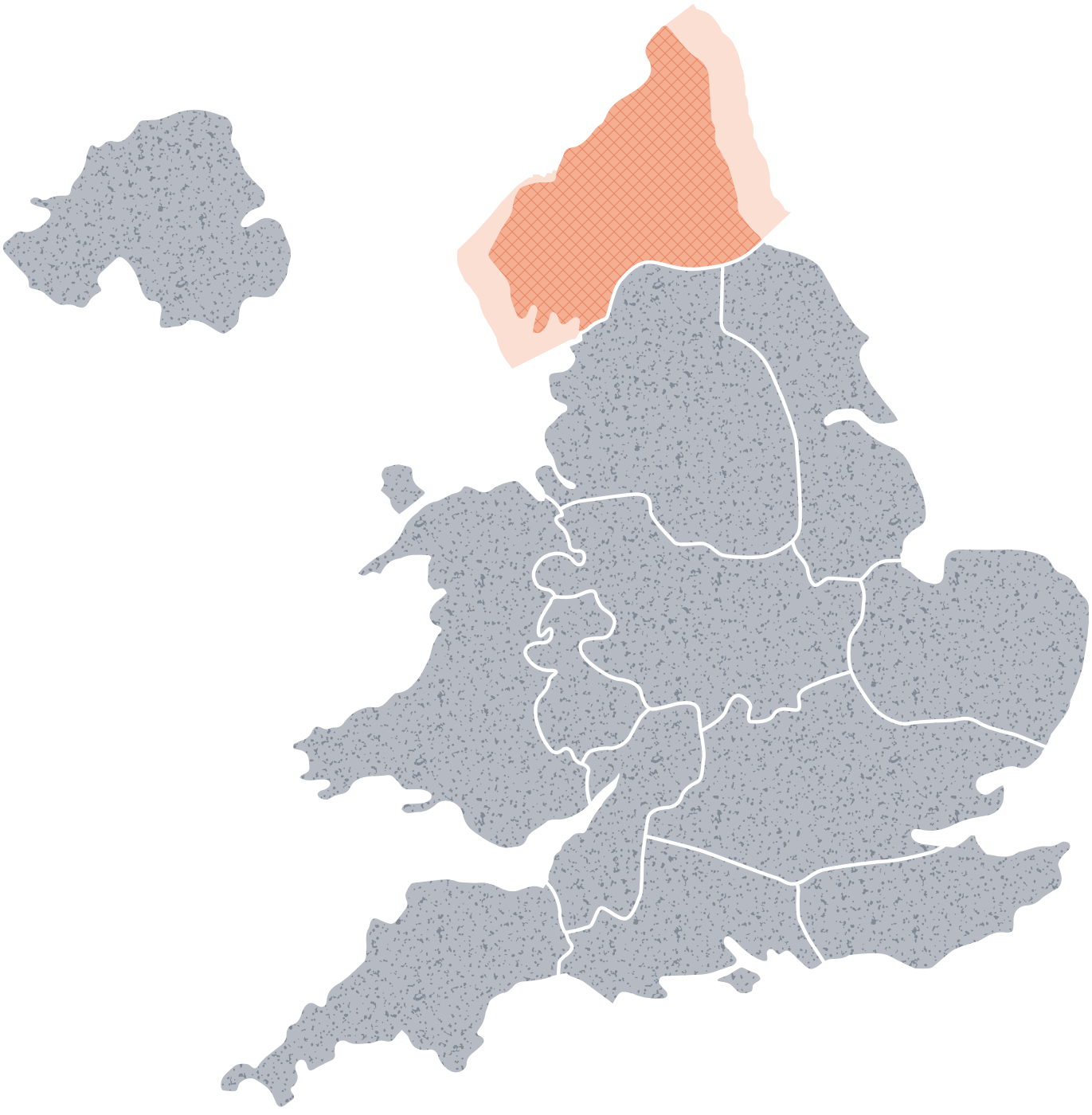
Radioactive Waste Management



Northern England

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 Cumbria, Northumberland, Durham and Tyne and Wear and parts of Lancashire and Yorkshire. The region includes the adjacent inshore areas which extend to 20km from the coast in the east and west and the Scottish border defines the northern boundary.

Subregions

To present the conclusions of our work in a concise and accessible way, we have divided the region into 5 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.

Northern England: 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. The information includes results from geological mapping, geophysical surveys and boreholes.

Available information for this region

The coverage of deep boreholes in the region is variable. Most of them are associated with mining or exploration for coal, iron, hydrocarbons or salt. In addition there are deep scientific investigation boreholes in Newcastle, Weardale and around Sellafield in west Cumbria. Geophysical investigations include studies of the Earth's gravity and magnetic fields and seismic surveys. Studies of the gravity field have been particularly important for identifying concealed granite bodies at depth. Seismic surveys have mainly been undertaken in the parts of the region which have been prospected for deep coal or hydrocarbons and have been particularly important for understanding the geology of the inshore areas and the Solway lowlands east into Northumberland. 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 groups: younger sedimentary rocks, older sedimentary rocks and basement rocks. These are summarised in Figure 2, which is a simplified rock column showing the oldest and deepest rocks at the bottom, 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 4, 5 and 6 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 7a to 7d show where in the region there are likely to be Rock Types of Interest for the development of a GDF 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). We refer to them as the younger sedimentary rocks. The Triassic Mercia Mudstone and Sherwood Sandstone Groups are found in the Solway Plain and extending into the inshore area around the Cumbrian coast. The Permian Cumbrian Coast Group underlies the Triassic rocks off the coast around Cumbria and is present in the Vale of Eden. Permian Zechstein Group rocks are present in the depth range of interest in the east of the region around Middlesbrough and Hartlepool. These younger sedimentary rocks largely comprise red sandstones and mudstones with associated evaporite sequences, including bodies of gypsum and anhydrite as well as rock salt (halite), with some limestones in the east. There are several units in the younger sedimentary rock sequence which contain mudstones and are likely to behave as LSSR. These are thicker and more persistent off the coast. There are also rock salt layers with potential to act as Evaporite host rocks in the same units in the inshore part of the region.

Older sedimentary rocks

Over much of the region, older sedimentary rocks of Carboniferous age (approx. 300 to 360 million years old) are present in the depth range of interest. We refer to these as the older sedimentary cover to the basement rocks below. The thickness of these rocks varies as a result of fault movements that took place while they were being deposited. They include the Pennine Coal Measures Group, Inverclyde Group and the Carboniferous Limestone Supergroup. The Pennine Coal Measures Group is present in the depth range of interest in the eastern part of the Northumberland and Durham Coalfield, extending off the coast, and in the West Cumbrian Coalfield, where it occurs in the inshore part of the region and beneath the Solway Lowlands. The Carboniferous Limestone Supergroup is present across much of the region. Close to the Scottish border, thick basaltic lavas occur in the depth range of interest interbedded with sandstones in the lower part of the Inverclyde Group. These lavas are potential HSR host rocks where they are sufficiently thick.

In the eastern half of the region a sheet of igneous rock, known as the Whin Sill, was intruded into the Carboniferous Limestone Supergroup later in the Carboniferous period. Although the Whin Sill is an igneous rock with low permeability and as such has been identified as a potential HSR by the BGS, we do not consider that it has the potential to host a GDF because it is generally only a few tens of metres thick and is cut by near-vertical joints which are likely to allow movement of groundwater.

Basement rocks

The basement rocks underlying the older and younger sedimentary rocks within the depth range of interest largely consist of weakly metamorphosed volcanic and sedimentary rocks of Silurian or Ordovician age (approx. 420 to 485 million years ago). They also include igneous bodies of granite or, more rarely, gabbro, which were intruded at depth into pre-existing rocks during Devonian to Ordovician times. Where the basement rocks are concealed beneath Carboniferous rocks, information on the rock types present comes mainly from geophysical studies and sampling from a small number of deep boreholes.

Basement rocks occur within the depth range of interest in 3 main areas:

- In Cumbria, basement rocks occur at the surface forming the fells of the Lake District extending downwards through the whole depth range of interest. In the surrounding areas they are present at depth but are generally overlain by Carboniferous rocks.
- A fault-bounded block centred on Weardale extending from the Vale of Eden to Newcastle-upon-Tyne.
- Devonian volcanic rocks (approximately 360 to 420 million years old) in the Cheviot Hills are approximately the same age as a number of granite bodies in the region and treated in this region as part of the basement geology.

Some of these basement rocks have potential as HSR host rocks.

Rock Structure

The region is affected by both major faulting and folding (Figure 8). The faults largely form the boundaries to sedimentary basins, such as the Vale of Eden and Solway Basin, and adjacent areas of higher basement rocks, such as the Lake District and Weardale granite.

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.

The younger sedimentary rocks mainly occur as rather flat-lying layers with gentle dips, but they are gently folded in the Solway Basin. Older sedimentary rocks are locally folded, especially in the sedimentary basins close to their major fault boundaries, and beds may be steeply dipping. Basement rocks over much of the area have been extensively folded and metamorphosed so that mudrocks have been converted to slates; many of the fine-grained volcanic rocks have also been metamorphosed and have become slaty, for example the green Borrowdale slates.

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 in the region. They include the Sherwood Sandstone Group and the Appleby Group sandstones which occur mainly in the coastal districts of Cumbria, the Solway Lowlands and the Vale of Eden. In addition, Zechstein Group limestones are important in the east and Carboniferous sandstones and limestones are important aquifers locally. In the west of the region the LSSR and Evaporite layers are likely to provide hydraulic separation between the deep and shallow groundwater even where they are not thick enough to host a GDF.

Basement rocks are mostly of very low permeability, except in the weathered and fractured zone within a few metres of the surface, which sometimes transmits water. Despite this, localised deep water movement does occur in basement rocks where there are open major fracture zones. In particular, the Weardale lead mining district has been explored for its geothermal potential, and the Eastgate borehole intersected a major mineral vein system within the Weardale Granite at about 430m depth, beneath the Carboniferous limestones which host mine workings. Large volumes of warm water were found to be flowing up the veins and are inferred to have circulated to depths of around 4km. Similar warm water flows have also been encountered in coal mines nearer to Newcastle, close to the major fault marking the northern limit of the basement block which includes the Weardale Granite (Figure 6). Detailed investigations near Sellafield in west Cumbria documented fresh water in sandstones of the younger sedimentary sequence, with saltwater present in the Borrowdale Volcanic Group basement rocks beneath. The saltwater is interpreted as being derived from the Irish Sea Basin to the west. Groundwater from depths greater than 400m is unlikely to be suitable as drinking water anywhere in the UK[1].

Mining is likely to have changed the original patterns of water movement in the central and eastern parts of the region and shallow groundwater may now circulate to greater depths within the depth range of interest than it did before mining. For instance in the Durham Coalfield the water levels in the Zechstein Group limestones were found to be coupled to those in the underlying Pennine Coal Measures Group as water levels rose after mine closure.

[1] Water Framework Directive UK TAG. Defining and reporting on groundwater bodies, 2012.

Resources

The region has been of historical importance for its mineral resources. The locations of areas mined below 100m are for metallic and vein minerals are shown in Figure 9a. The locations of coal mines below 100m and Coal Authority Licence Areas are shown in Figure 9b. Locations of areas with Petroleum Exploration and Development Licences[2] are shown in Figure 9c. Areas of historic mining shallower than 100m and evaporite mines below 100m are shown in Figure 9d.

The major coal mining districts were the Northumberland and Durham Coalfield in the east and the West Cumbrian Coalfield in the west. Both extend into the inshore area with the coal seams becoming progressively deeper further from the coast.

Iron ore was mined extensively in west and south Cumbria and a number of other metals have been mined within the Lake District, such as copper mines on the flanks of Sca Fell and The Old Man of Coniston, with some mines extending to below 100m.

The North Pennine Orefield (Figure 9d), centred on Weardale, has been mined for lead, zinc and fluorite. Most mines are shallow but some fluorite mines extend below 100m and zinc and lead resources have been identified recently at around 500m below NGS datum (A on Figure 9d).

Gypsum and anhydrite have been mined in areas around Whitehaven in the west, Middlesbrough in the east, and in the Vale of Eden, which continues to be a centre for gypsum production. Mines often extend to 200 to 300m below the surface (see Figure 9d). Rock salt (halite) and potash have mainly been produced in the south-east of the region, around Middlesbrough and Hartlepool, and these deposits extend into the Eastern England region.

Cavities produced by solution mining of salt are now used for gas storage on Teesside. Part of the Billingham anhydrite mine, north of Stockton-on-Tees, is now licensed for toxic waste disposal.

The areas where concentrations of deep exploration boreholes would need to be considered in the siting of a GDF are shown in Figure 10.

[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. Earthquakes in this region have been recorded over the past few hundred years with a similar frequency to the other regions in the UK. Only 5 earthquakes with a magnitude of 4.0Mw or greater have been recorded in the past 500 years. The largest modern earthquake in the region was the magnitude 4.4Mw Longtown earthquake of 1979, which caused minor damage to chimneys and roofs in parts of Carlisle.

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, and was entirely covered by ice sheets during the last 2 major UK glaciations, known as the Devensian and the Anglian. Much of the region also experienced a later highland-scale glaciation ending 11,000 years ago and glaciers spilled over to give rise to lowland-scale glaciation nearby. The precise siting and design of a GDF would need to consider the potential impacts of glaciation and permafrost during future ice ages. These may include increased erosion and changes to groundwater movement.

The coastal area in the east 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

Further 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 Northern England region as defined for the purpose of National Geological Screening.

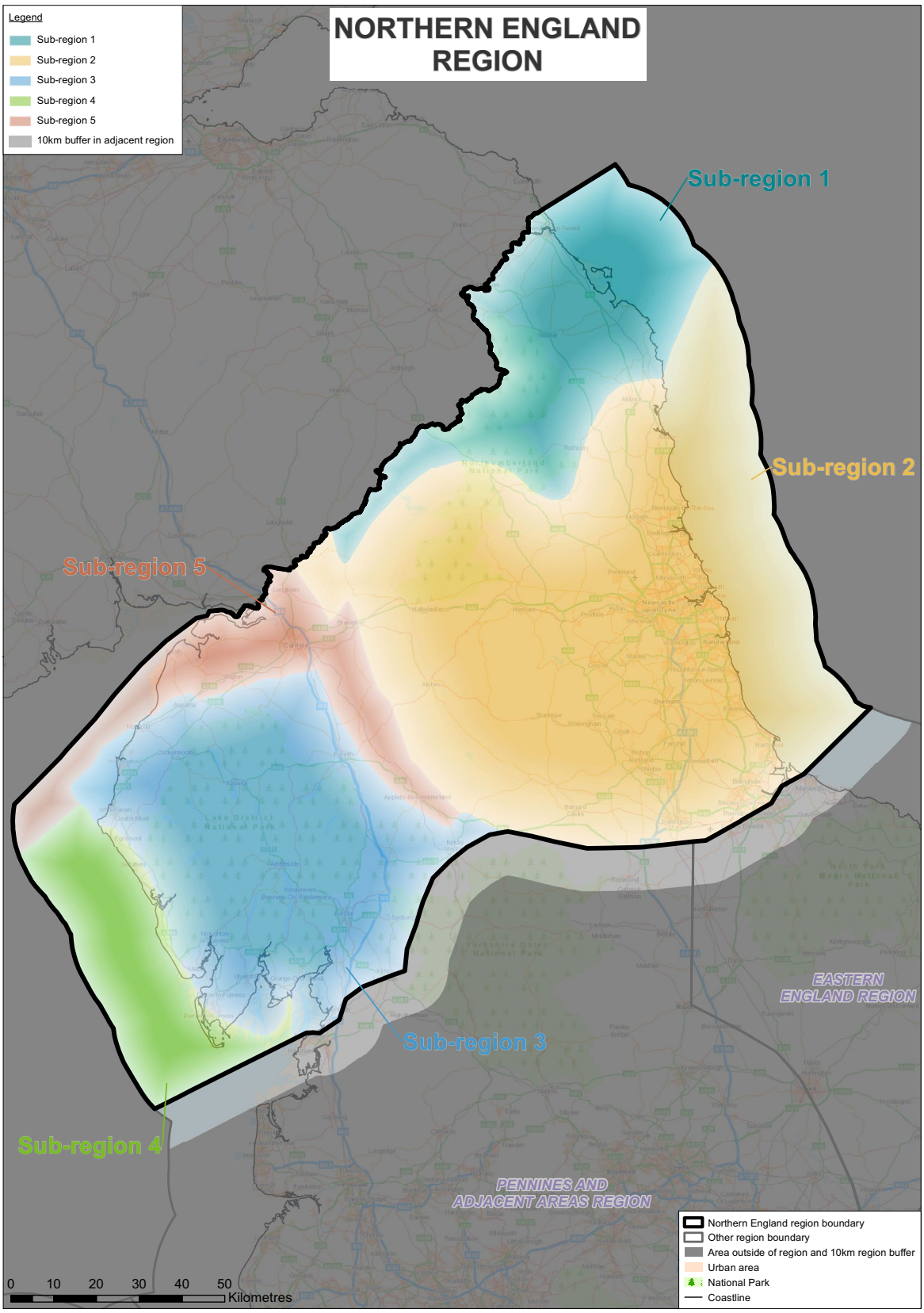


Figure 2 Table illustrating the sequence of the major rock units present in the Northern England region and their possible significance for the siting of a GDF.

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Younger sedimentary rocks	Jurassic (145.0 – 201.3)	Lias Group	Not applicable as not within depth range of interest	Not applicable as not within depth range of interest		
	Triassic (201.3 – 251.9)	Mercia Mudstone Group	mudstone with local siltstone and evaporite deposits of anhydrite, gypsum and halite	✓		✓
		Sherwood Sandstone Group including St Bees sandstone	sandstone, siltstone and mudstone			
	Permian (251.9 – 298.9)	Cumbrian Coast Group (west) or Zechstein Group (east)	mudstone and sandstone with anhydrite, gypsum and/or rock salt. Limestone in east.	✓		✓
		Appleby Group (west) or Rotliegendes Group (east)	sandstone and conglomerate			
Older sedimentary and related rocks	Carboniferous (298.9 – 358.9)	Whin Sill	dolerite and basalt			
		Warwickshire Group	sandstone and siltstone with mudstone	✓		
		Pennine Coal Measures Group	mudstone, siltstone, sandstone and coal			
		Millstone Grit, Yoredale and Border Groups	sandstone, siltstone, limestone and mudstone			
		Inverclyde Group	sandstone, siltstone and mudstone with conglomerate, anhydrite, limestone and basalt		✓	
		Carboniferous Limestone Supergroup	limestone with mudstone, siltsone and conglomerate			
Basement	Devonian (358.9 – 419.2)	Lake District Batholith (in part), Cheviot and Weardale granites	granite		✓	
		Cheviot volcanics	volcanics		✓	
	Silurian (419.2 – 443.8)	Windermere SuperGroup (including Kendal and Dent Groups)	weakly metamorphosed mudrock with siltstone and sandstone		✓	
	Ordovician (443.8 – 485.4)	Lake District Batholith (in part)	granite		✓	
		Borrowdale and Eycott Volcanic Groups	weakly metamorphosed lavas and pyroclastic rocks		✓	
		Skiddaw Group	weakly metamorphosed slates and sandstones		✓	

Figure 3 Generalised geological map showing the distribution of rock units in the Northern England 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 4, 5 and 6. See Figure 2 for the key to the rock types shown.

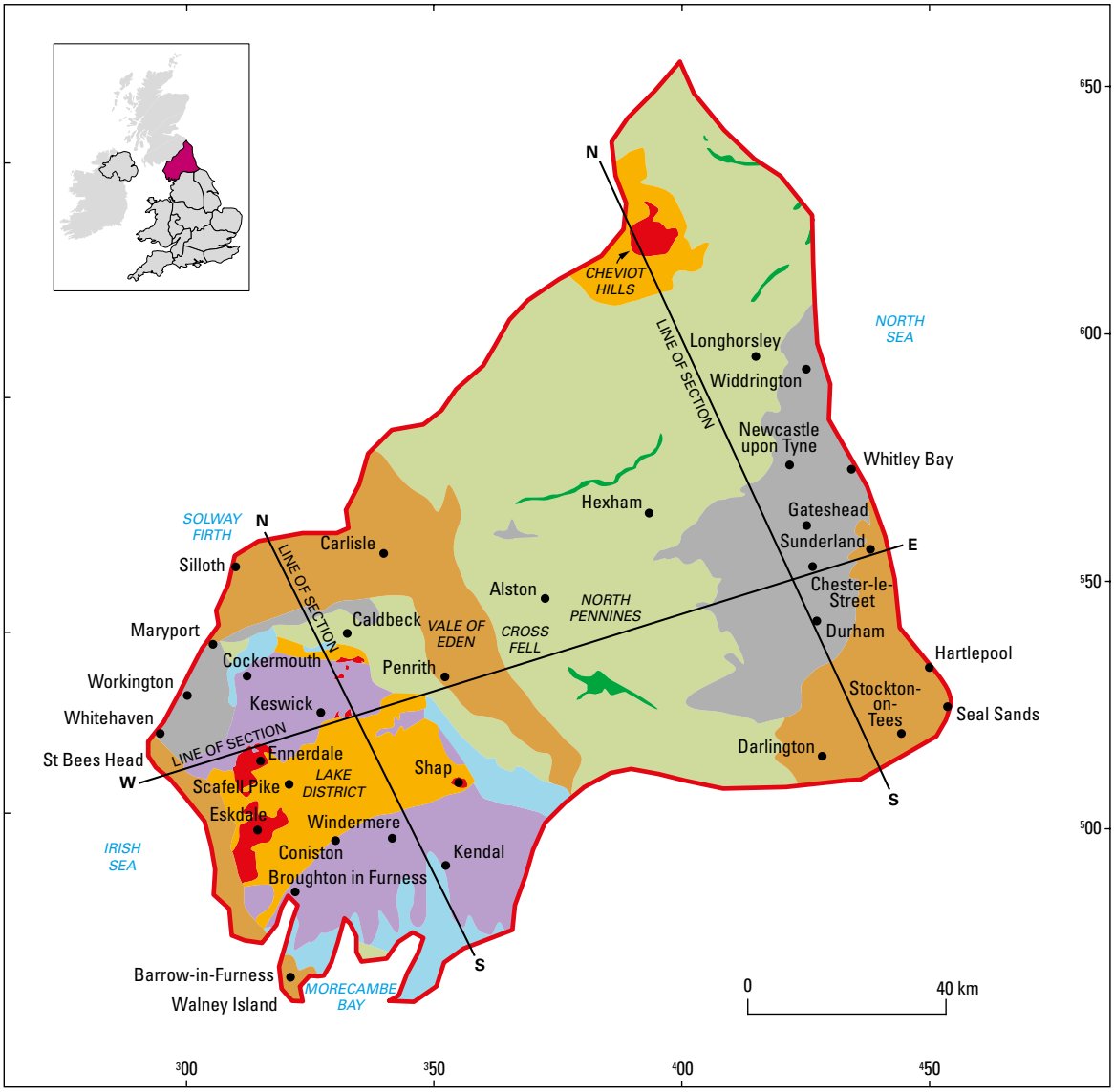


Figure 4 Schematic cross-section from the Irish Sea to the North Sea through the Northern England region. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

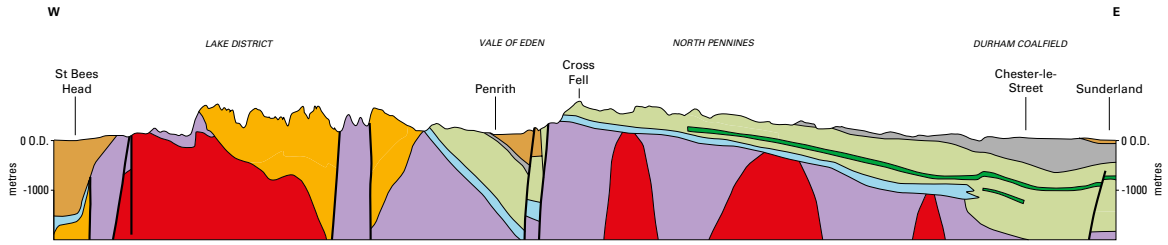


Figure 5 Schematic cross-section from the Solway Firth to north Lancashire through the Northern England region. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

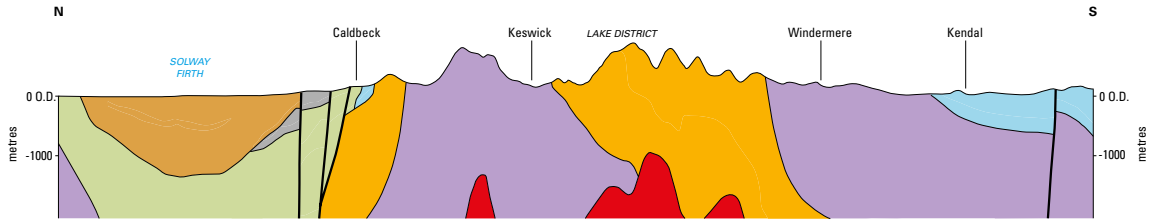


Figure 6 Schematic cross-section from the Cheviot Hills to County Durham through the Northern England region. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types shown.

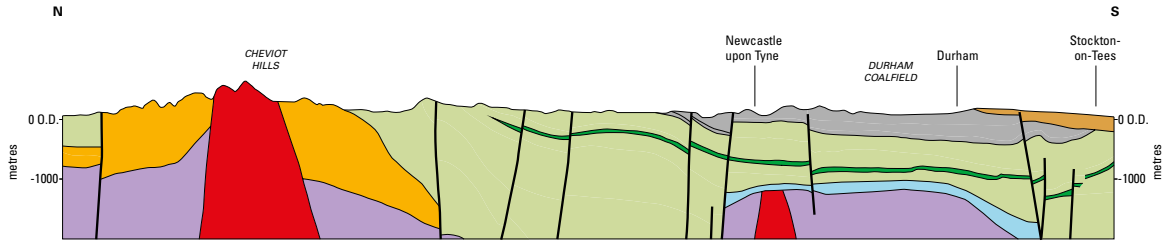


Figure 7a The areas of the Northern England region where any of the 3 Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

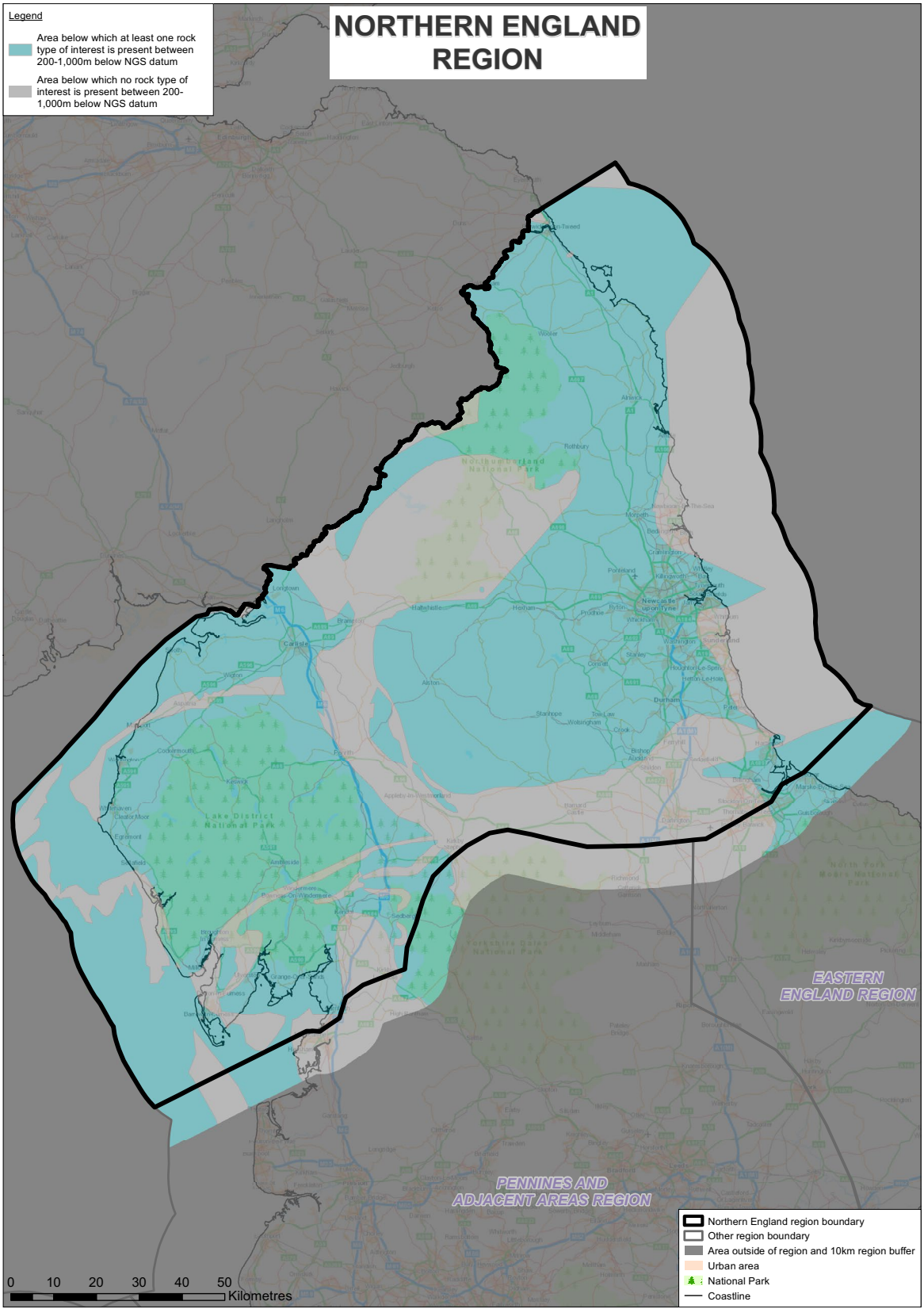


Figure 7b The areas of the Northern England region where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

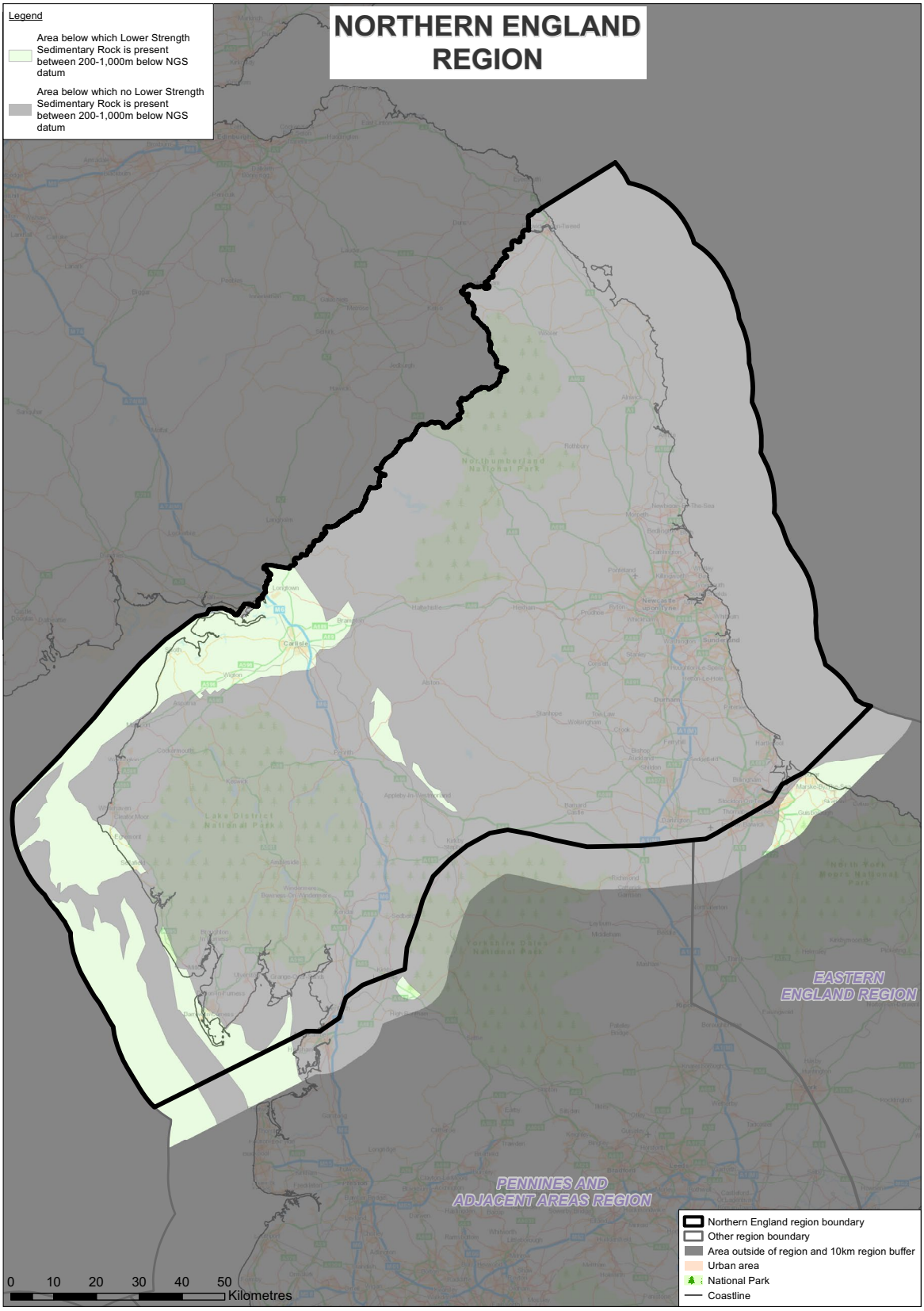


Figure 7c The areas of the Northern England region where Higher Strength Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

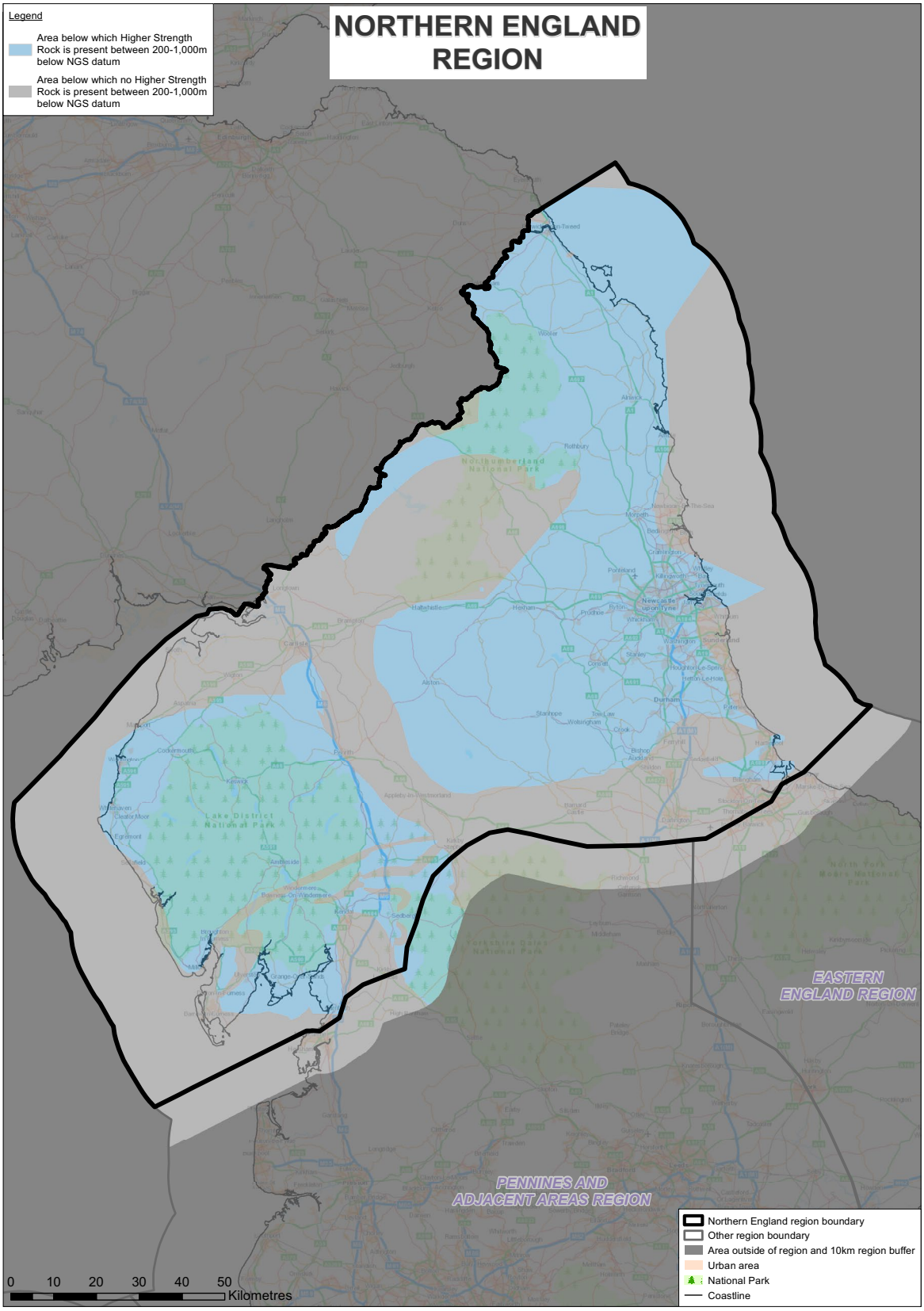


Figure 7d The areas of the Northern England region where Evaporite Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

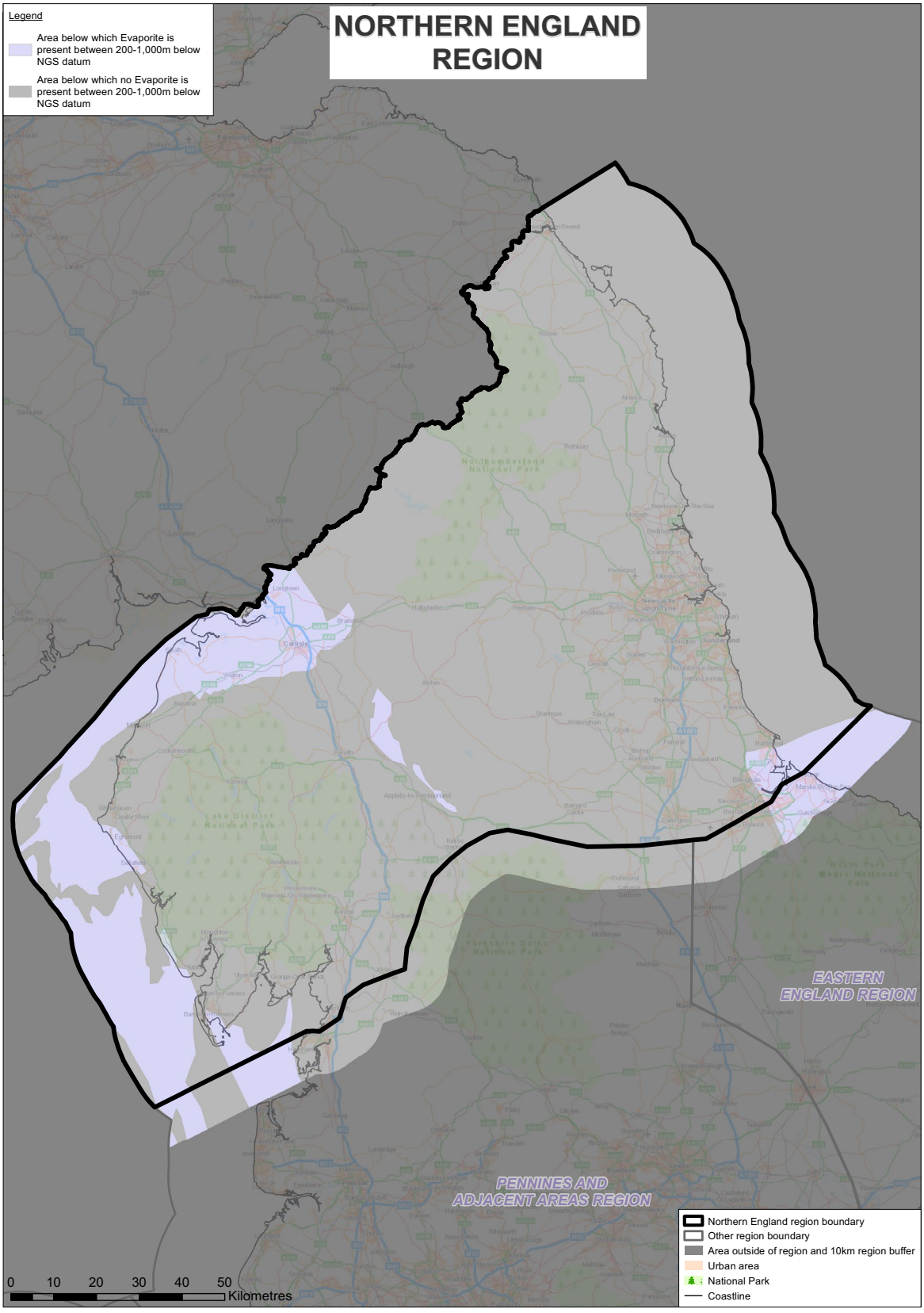


Figure 8 Major faulting and folding in the Northern England region.

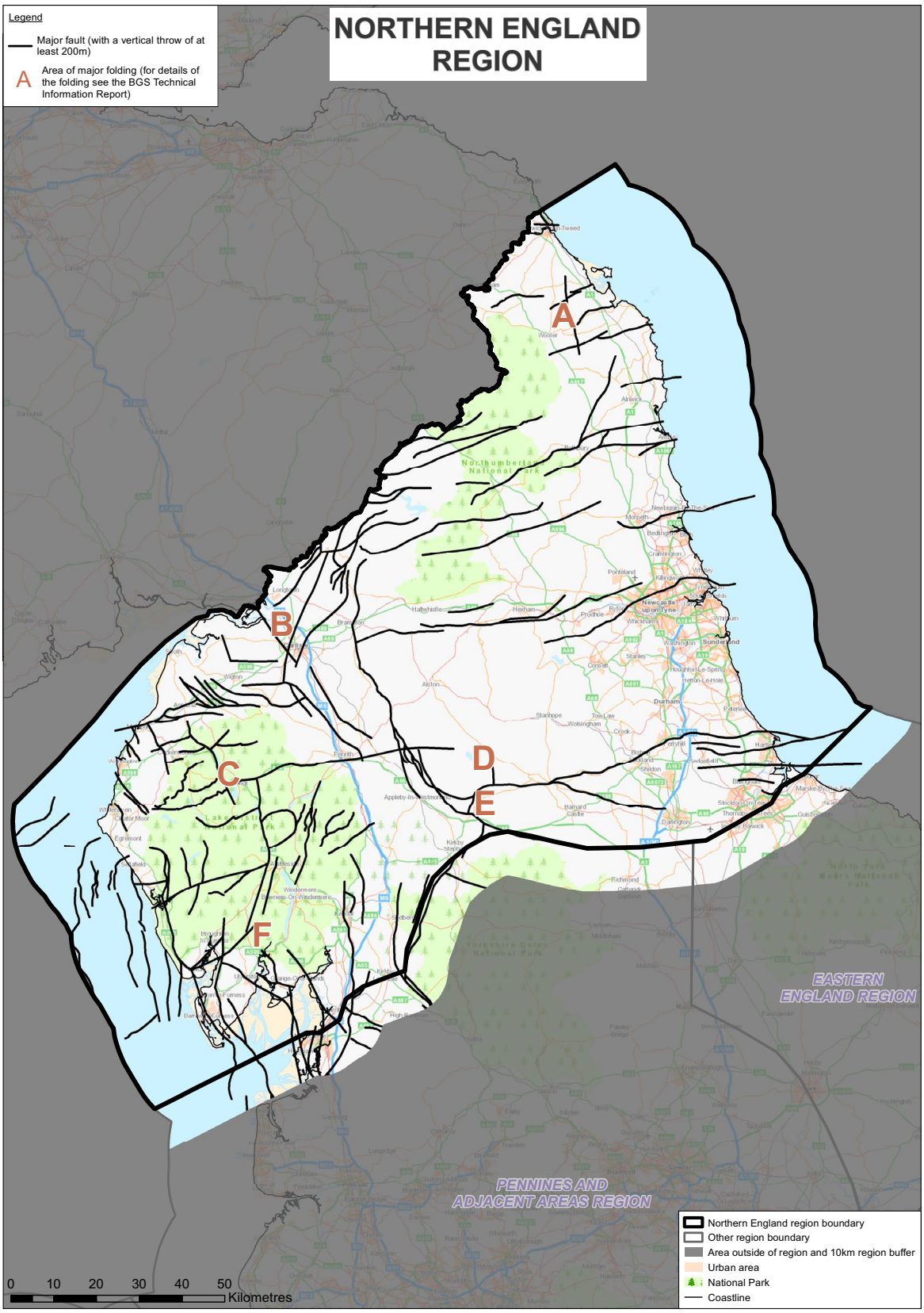


Figure 9a Areas of the Northern England region with metallic and vein mineral mines present below 100m.

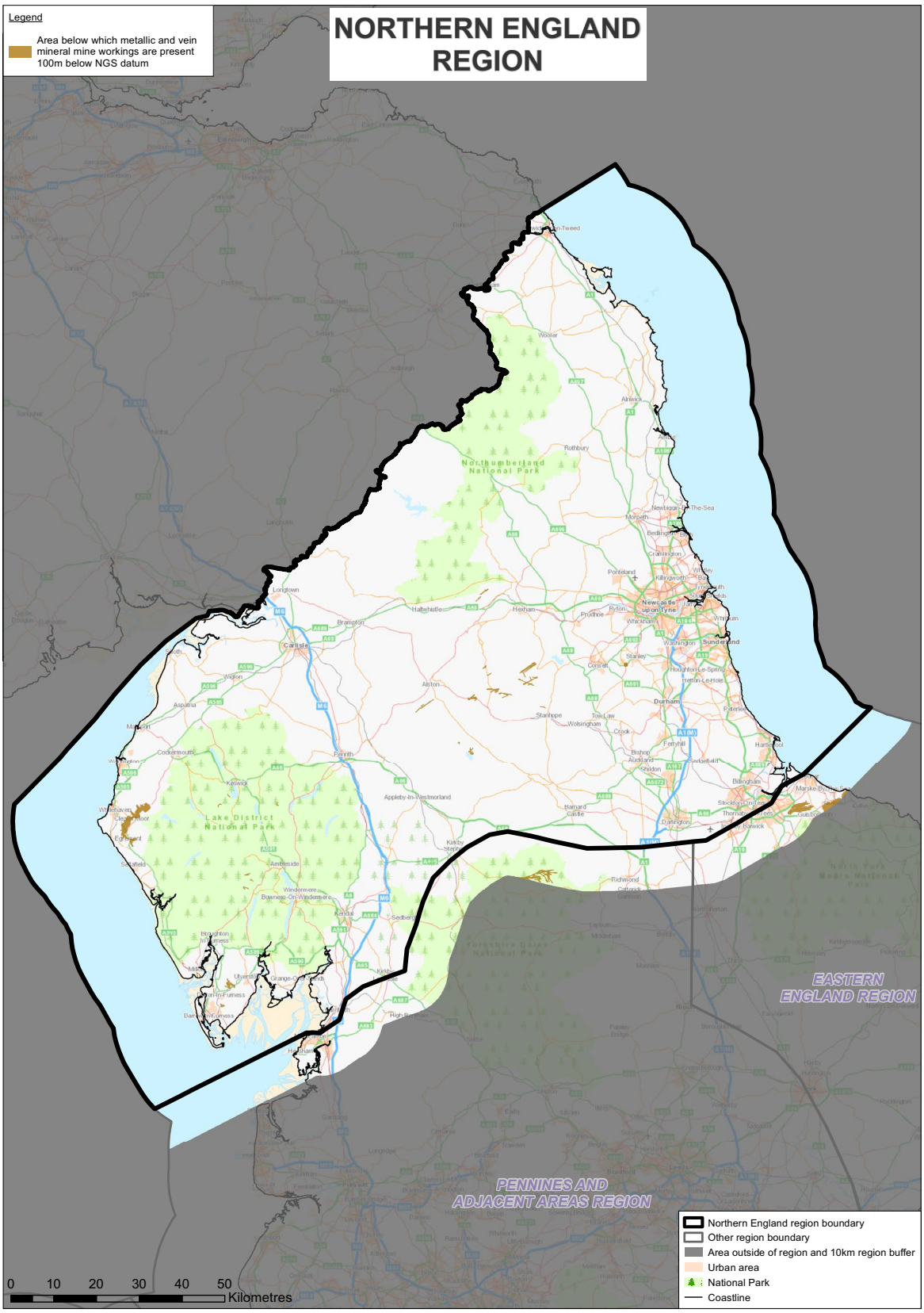


Figure 9b Areas of the Northern England region with coal mines more than 100m deep and Coal Authority Licence Areas.

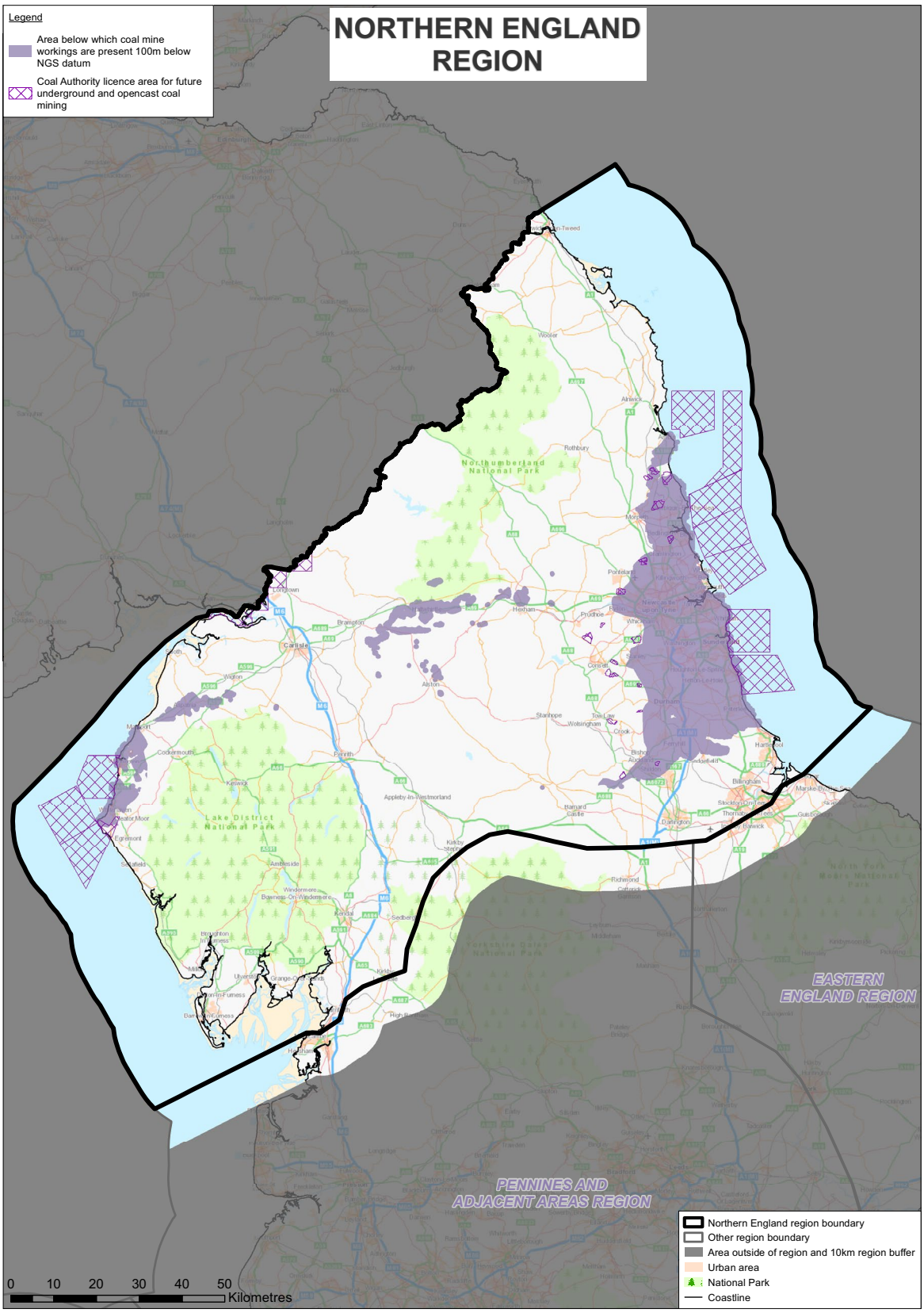


Figure 9c Areas of the Northern England region with Petroleum Exploration and Development Licences.

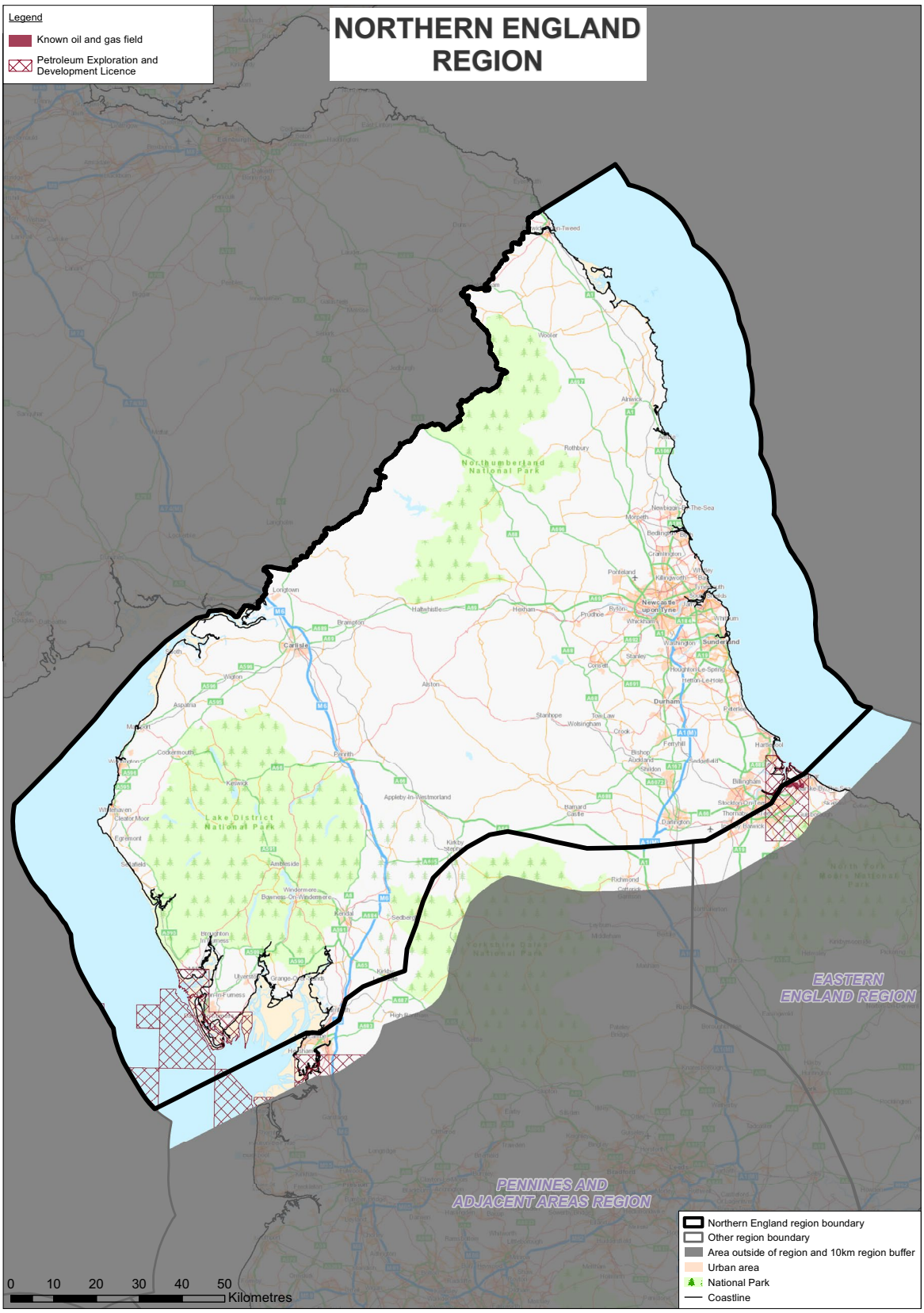


Figure 9d Areas of the Northern England region with historical iron ore mines less than 100m deep, known mineral prospects and evaporite mines deeper than 100m.

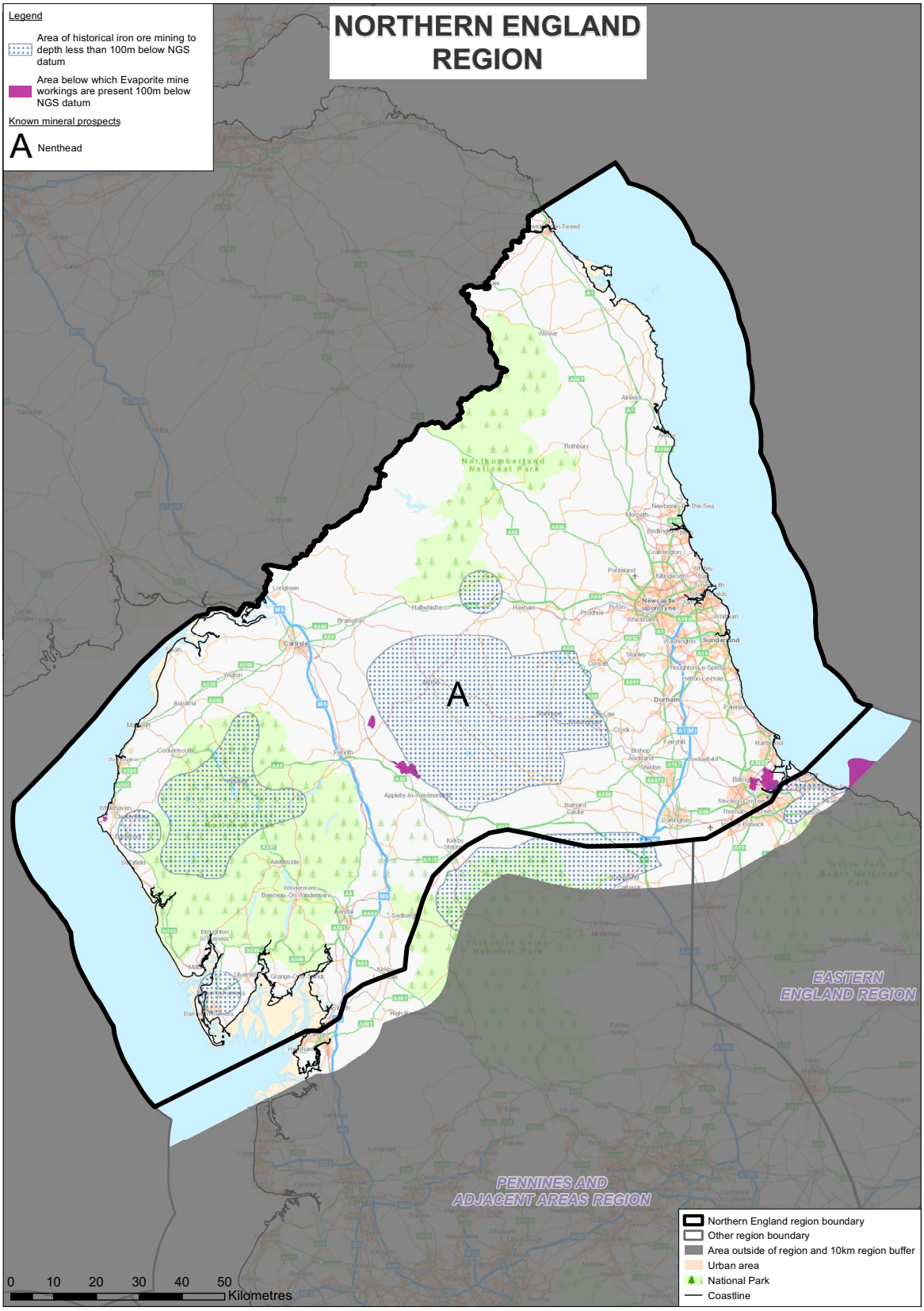
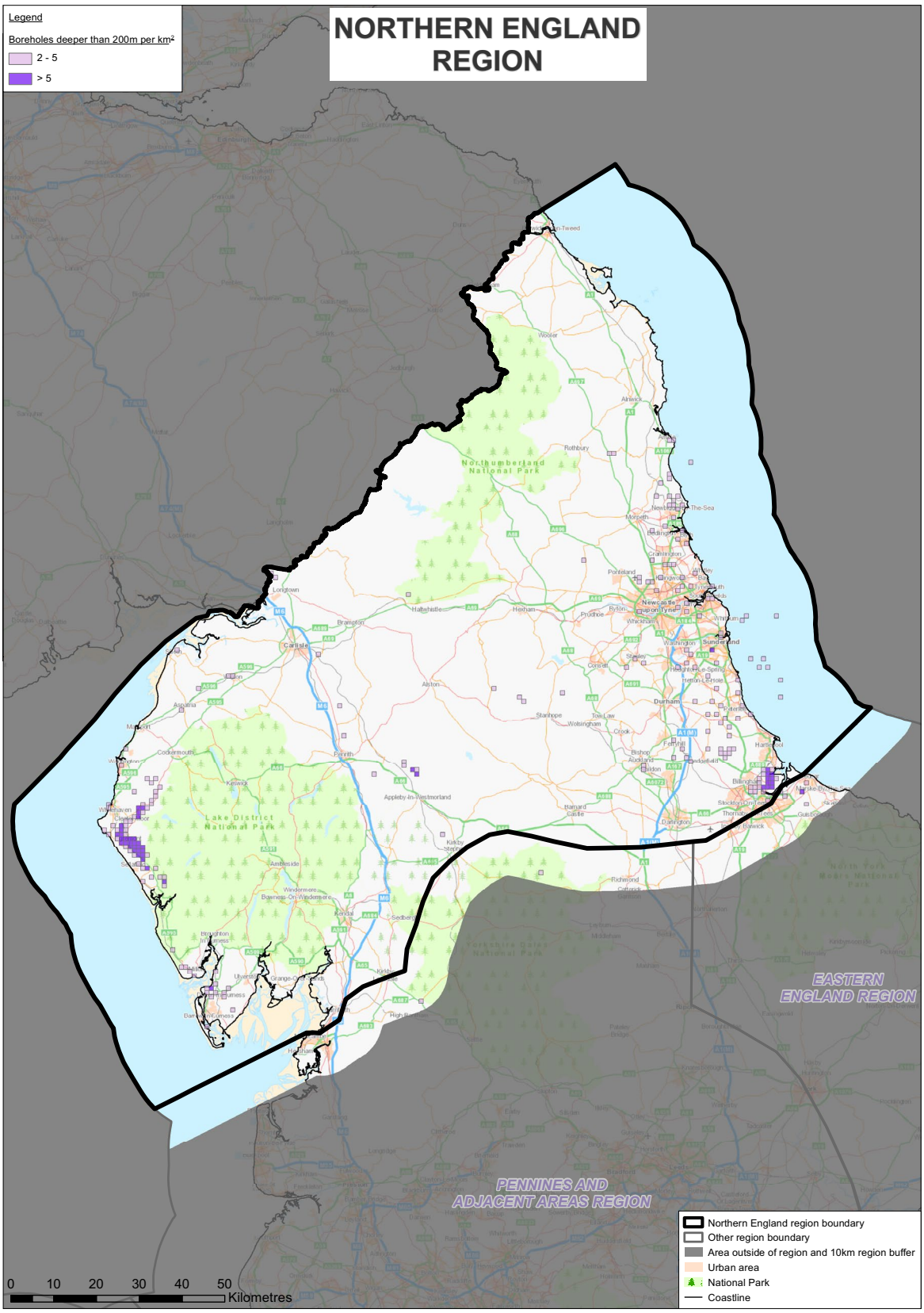


Figure 10 Areas in the Northern England region with concentrations of deep exploration boreholes.



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.

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.

Fracture
A crack in rock. Fractures can provide a pathway for fluids, such as groundwater or gas, to move in otherwise impermeable rock.

Fracture zones
A region of closely spaced cracks or faults in a volume of rock. Fracture zones may provide a pathway for fluids to move underground in rocks that would otherwise be impermeable.

Gabbro
Dark-coloured, coarse crystalline igneous rock rich in iron and magnesium.

Granite
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.

Igneous
One of three main rock types (the others being sedimentary and metamorphic), consisting of hard, dense rocks made up of interlocking crystals. They form due to cooling of magma deep within the crust beneath volcanoes, or as lavas erupted at the surface.

Joints
A crack in rock. These cracks can provide a pathway for fluids, such as groundwater or gas to move in otherwise impermeable rock.

Lavas
Molten magma that has been extruded (or erupted) onto the earth's surface. Lava quickly solidifies to form igneous rocks. Different rocks will form depending on the composition of the lava (e.g. basalt or andesite).

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.

Potash
The collective term for potassium-bearing evaporite minerals. Potash is mined in the UK for use in fertilizer.

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.

Pyroclastic
Deposits of solid material erupted explosively from a volcano, ranging in size from large blocks and boulders to very fine ash. The citizens of Pompeii were buried beneath thick clouds of hot pyroclastic material in 79AD.

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.

Seismic survey

Geophysical method that produces an image of the subsurface by transmitting shock waves, or seismic energy, into the ground and measuring the pattern of energy that is reflected back to the surface. Widely used by the resource industries to provide information on the composition and structure of the underground geology.

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.

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.

Radioactive Waste Management

Building 587
Curie Avenue
Harwell Oxford
Didcot OX11 0RH

T 03000 660100
www.gov.uk/rwm