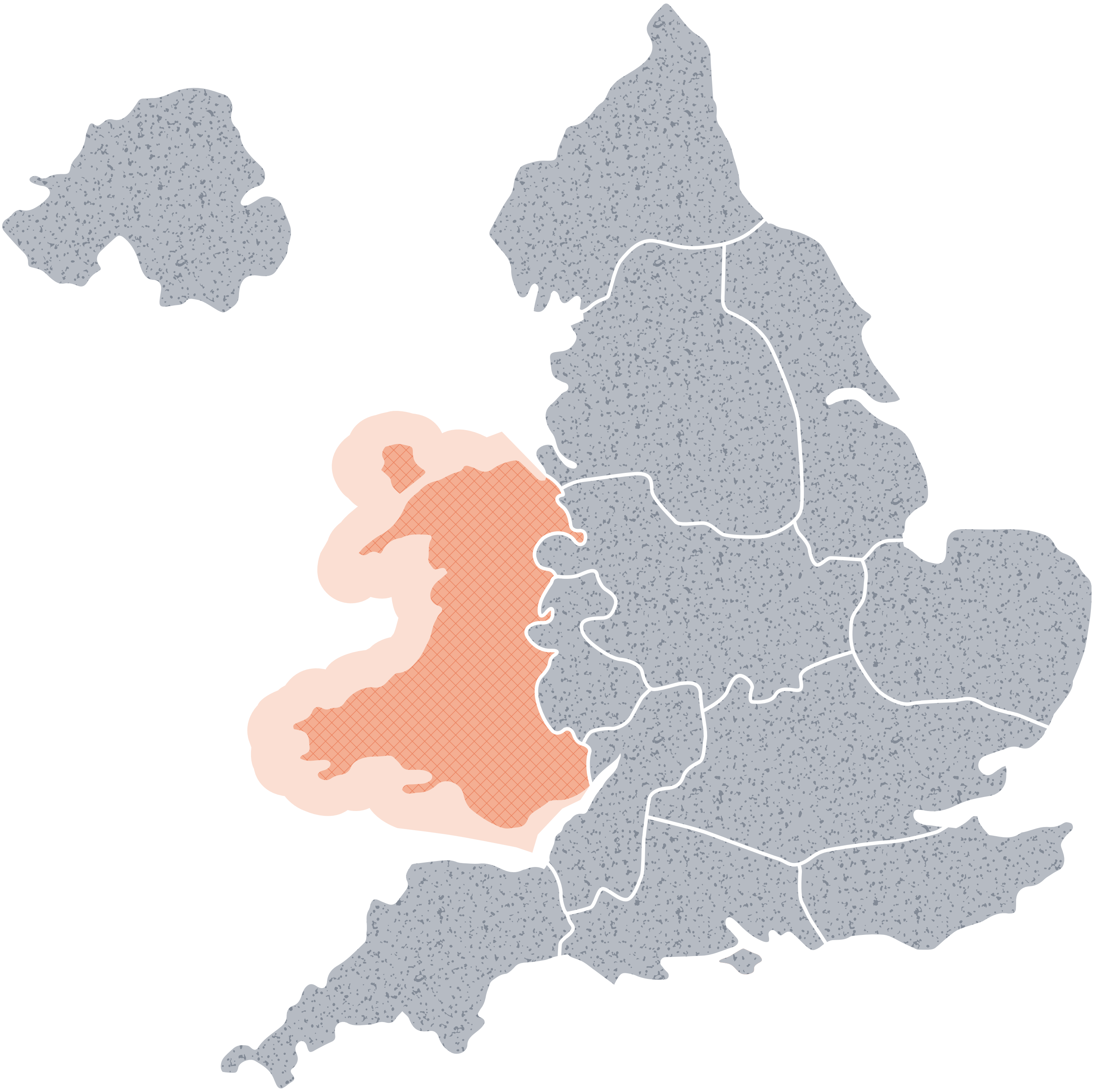
Radioactive Waste Management



Wales

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 Wales and includes 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 Wales into 6 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.

Wales: summary of the regional geology

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

Available information for this region

The surface geology of Wales has been mapped over many years and is generally well known, although in many places there is a thin cover of sediments, mostly dating back no further than approximately 1.8 million years which has hindered studies of the underlying rocks. There is much less information about the geology at depth; onshore, only the coalfield areas have been drilled to any great extent and most other deep boreholes are in the inshore part of the Bristol Channel and Cardigan Bay. In total, 32 boreholes extend below 1,000m, mainly in these areas. Geophysical investigations include studies of the Earth's gravity and magnetic fields and seismic surveys and are also very limited in extent, with onshore data almost exclusively about areas around the coalfields. There are also a number of seismic surveys off the coast, mainly in the southern Irish Sea and Bristol Channel. There are a number of shallower boreholes that provide information on 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 Wales we have divided them into 3 main groups: younger sedimentary rocks, older sedimentary rocks, and basement rocks, as 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 country showing where the major rock units occur at the surface. Figures 4, 5 and 6 present schematic vertical cross-sections through the country. 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 these are likely to occur. It is notable that the rocks present in the depth range of interest in the inshore part of the region are often quite different from those found on the coast.

Younger sedimentary rocks

The youngest rocks occurring in the depth range of interest for screening are sedimentary rocks of Miocene to Permian age (approximately 5 to 300 million years old), which occur mainly in the inshore part of the region. These are referred to here as the younger sedimentary rocks comprising sandstones, siltstones and mudstones with minor limestones and contain evaporite sequences. There are thick sequences of younger sedimentary rocks off most of the Welsh coast, apart from Anglesey and the south coast of Pembrokeshire with evaporites in the Bristol Channel, St George's Channel and east of Anglesey.

There are several units in the younger sedimentary rock sequences which contain thick mudstones and are likely to behave as LSSR; some evaporites may also contain sufficiently thick rock salt (halite) layers to act as Evaporite host rocks.

Older sedimentary rocks

Sedimentary rocks of Carboniferous and Devonian age (approx. 300 to 420 million years old) are widespread in south, south-east and north-east Wales and comprise the older sedimentary cover to the basement rocks. Carboniferous rocks include the Warwickshire, Pennine Coal Measures and South Wales Coal Measures Groups, which are dominated by coal, mudstone and sandstone, the sandstones and shales of the Millstone Grit or Marros Group, and the Carboniferous Limestone Supergroup of south and north Wales. The underlying Upper and Lower Old Red Sandstone Groups and related Devonian rocks occur in the south-east giving rise to the characteristic hills of the Black Mountains. There are very few rocks with potential to host a GDF in the older sedimentary rocks.

Basement rocks

A wide range of rocks form the basement to the overlying sedimentary rocks. Beneath most of Wales, there is a sedimentary sequence comprised of Silurian, Ordovician and Cambrian rocks (approx. 420 to 540 million years old) many kilometres thick which has been intensely folded and metamorphosed on a regional scale. In addition to rocks of sedimentary origin there are also thick, extensive deposits of volcanic rocks (lava flows and tuffs), mainly of Ordovician age (approx. 445 to 485 million years old). As a result of this regional metamorphism and folding, the original mudrocks and fine-grained tuffs are now slates. There are also some occurrences of more highly metamorphosed rocks, such as schists, and some of these are Precambrian age (older than approximately 540 million years old).

Most of the basement rocks are potential HSR host rocks, but there is very little information in the depth range of interest to confirm this. The presence of thin layers of variable properties in some rock units are likely to make it difficult to locate suitable, reasonably uniform rock volumes at the right scale to host a GDF in some areas.

In the east, Silurian rocks beneath the Lower Old Red Sandstone Group, have not become slaty, and so are treated here with the older sedimentary rocks and not the basement rocks.

Rock structure

The younger sedimentary rocks are generally not affected by major folding but occur in basins bounded by major faults, including faults parallel to the coastline (Figure 8). These faults, which first developed as the Triassic and Permian (approx. 200 to 300 million years old) sediments were being deposited, define the limits to these sedimentary rock bodies but there is relatively little faulting within them.

The older sedimentary rocks are intensely deformed in south Wales, especially south of the Variscan Front, a line extending from St Bride's Bay through Cardiff and continuing east into England related to a major plate tectonic event about 300 million years ago. Further north, in Brecon and in north Wales, there are important bounding faults but less folding.

The basement rocks across much of Wales were extensively folded in an earlier tectonic event which affected Silurian and older rocks across most of the country. The folding accompanied metamorphism and in addition to large fold structures indicated in Figure 8, the rocks were folded throughout on a smaller scale of metres to tens and hundreds of metres. Often, where the layers have contrasting mechanical properties, the folding is accompanied by small scale faulting and this may impact groundwater movement. Much of central and northern Wales is characterized by slates that have been folded so intensely that original bedding is almost completely obliterated and replaced by a pervasive 'slaty cleavage'. The Dynorwig storage hydroelectricity plant at Llanberis is excavated in a mountain composed entirely of slate.

South-east of the Welsh Borderland Fault System and adjacent to the Welsh Borderland region, the basement rocks were not affected by the tectonic events and are relatively undeformed. As a result the mudstones have not been transformed to slates like those to the north and west.

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. Over large parts of Wales, water supplies mainly come from surface sources rather than underground ones. Basement rocks are mostly of very low permeability, except in the weathered and fractured zone within a few metres of the surface, which sometimes retains and transmits sufficient water to supply small communities. Wells extend less than 50m from the surface, with most production from the top 30m.

There are several principal aquifers present within 400m of the surface but groundwater is important in only 2 parts of the country. In the north-east, in the Vale of Clwyd, the Sherwood Sandstone Group is a major source of water, while in South Wales, the Carboniferous Limestone aquifer and a permeable unit of the Mercia Mudstone Group overlying it provide an important source of groundwater around the edge of the coalfield. Upper and Lower Old Red Sandstone Group rocks are also used as a source of water in parts of Wales.

Where they are present, the LSSR layers in the younger sedimentary sequence are likely to act as a barrier to vertical groundwater movement between deep and shallow groundwater, even where they are not thick enough to host a GDF. There is some evidence for deeper groundwater flow feeding mineral springs in central Wales, but only Taffs Well (north-west of Cardiff) is a thermal spring (Figure 9b). Groundwater from depths greater than 400m is unlikely to be suitable as drinking water anywhere in the UK [1].

Mining has changed the original patterns of water movement in several areas but the effect is most widespread in the South Wales Coalfield where shallow groundwater is now likely to circulate to greater depths within the depth range of interest than it did before mining. There has also been major modification to drainage patterns by lead mining in the north, near Mold and Holywell.

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

Resources

Wales has a long history of metal and coal mining, and the locations of mines extending below 100m are shown in Figures 9a and 9b. Coal mining in the South Wales Coalfield commonly extended to depths below 100m, whereas in north Wales deep coal was only present at the eastern margin of the coalfield near Wrexham and Queensferry. Iron mining extended below 200m north-west of Cardiff until 1971 and there were deep mines for lead and zinc, extending below 300m, in the central Wales and north east Wales orefields. Parys Mountain was a major copper mine in Anglesey.

Figure 9c shows where there are Petroleum Exploration and Development Licences including those related to coal bed methane in and around the coalfields and shale gas potential in the south-east, between Newport and Chepstow. There are Coal Authority Licence Areas in South Wales and off the North Wales coast (Figure 9b).

The full extent of the historic mining areas is also shown in Figure 9d, but is not relevant to the siting of a GDF as the mines are shallower than 100m. In recent times there has been widespread prospecting for copper and related metals in 2 areas of Anglesey and Snowdonia, but there are no current plans to exploit these resources (A and B on Figure 9d).

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

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. Most of Wales experiences small earthquakes with a similar frequency to other parts of the United Kingdom, but there have been a number of earthquakes on the Llŷn Peninsula, including the 1984 magnitude 5.1Mw earthquake, which had a hypocentre below 20km. Historic earthquakes in this area appear to have had epicentres close to that of the 1984 earthquake. There have also been a number of earthquakes up to magnitude 4.9Mw in south Wales, around Swansea, Carmarthen and Pembroke.

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.

All of Wales was affected by continental-scale glaciation during the Pleistocene epoch, with the last major UK glaciation, known as the Devensian, extending over virtually all of the country around 29,000 to 15,000 years ago. The earlier, Anglian, ice sheet also covered the entire country. The mountainous parts of Wales developed ice caps during additional highland-scale glaciations and were last covered by ice around 11,000 years ago. 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 areas of the country are 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 most of Wales can be found in the BGS Regional Summary, with additional detail in the BGS Regional Guide for Wales; however information about some parts of east Wales is incorporated in the BGS publications for the Welsh Borderland region and the Bristol and Gloucester region. The guides also provide details about many of the sources of information underpinning the TIR.

Figure 1 Subregions of Wales as defined for the purpose of National Geological Screening.

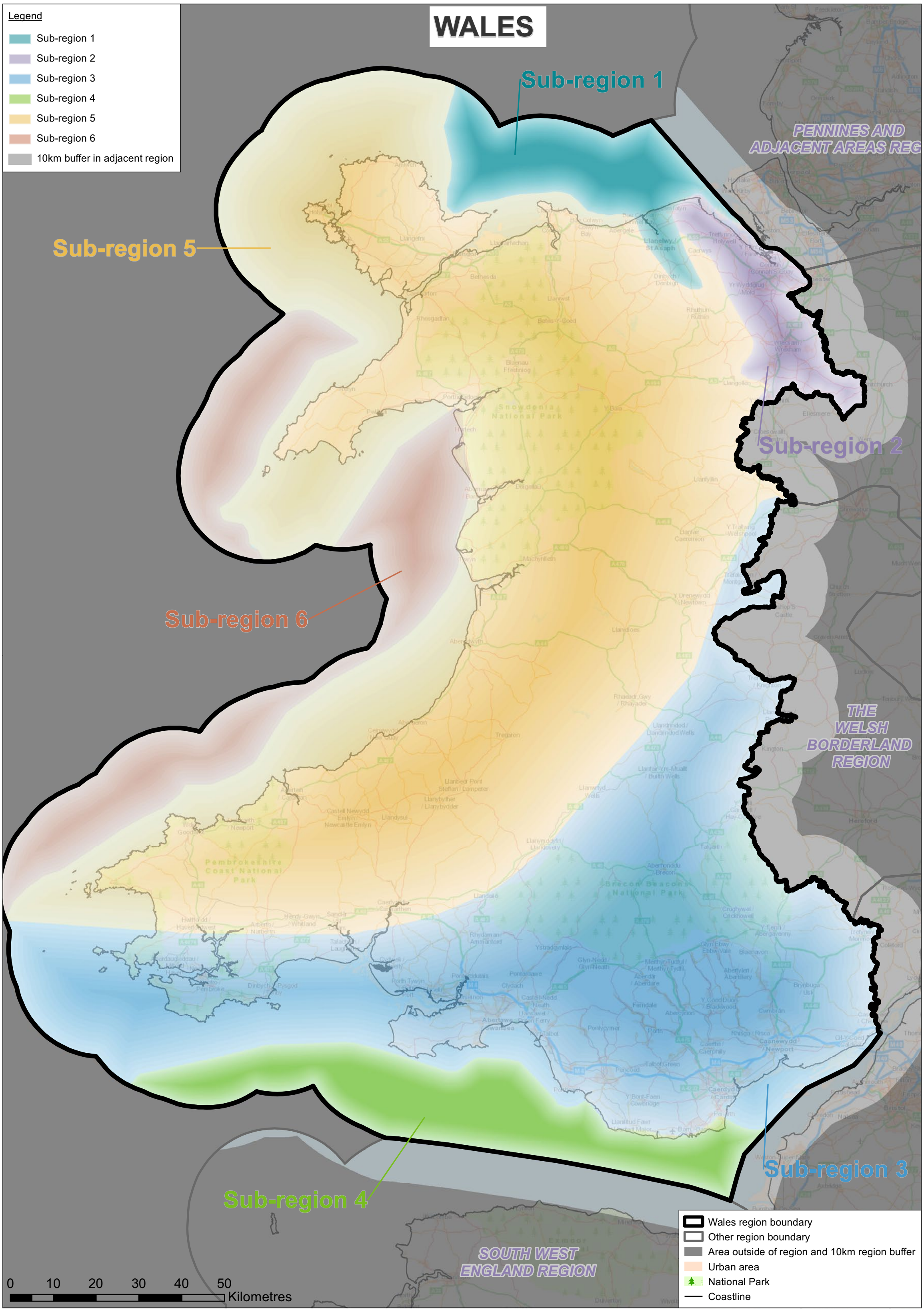


Figure 2 Table illustrating the sequence of the major rock units present in Wales and their possible significance for the siting of a GDF [2].

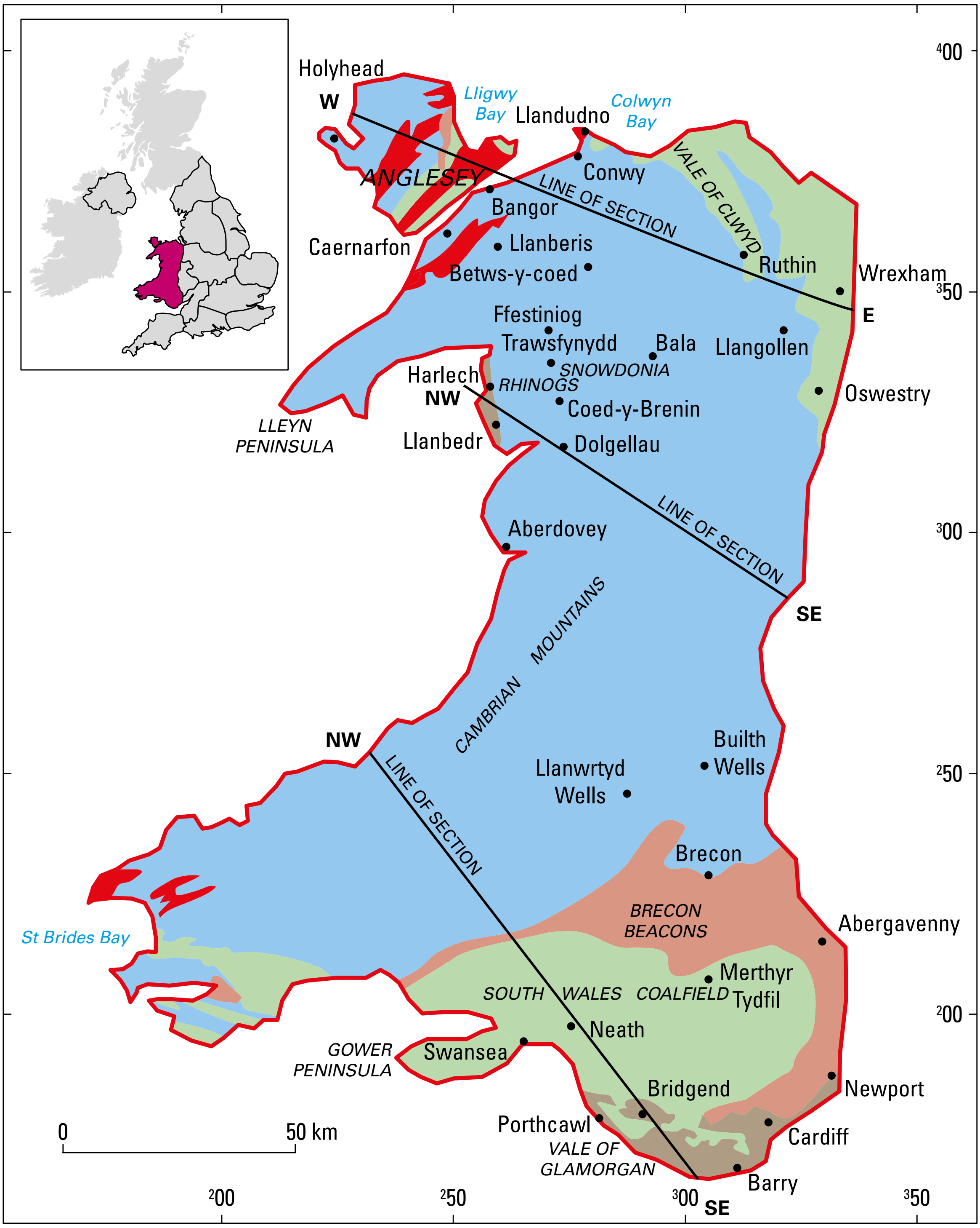
	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Younger Sedimentary Rocks	Neogene / Paleogene (2.6 – 66.0)	Eocene – Miocene sediments Undifferentiated	conglomerate, siltstone, sandstone and claystone	✓		
		Palaeogene rocks undifferentiated	conglomerate, siltstone, sandstone and claystone	✓		
	Jurassic (145.0 – 201.3)	Upper Jurassic rocks undifferentiated (including Kimmeridge Clay Formation)	mudstone with limestone and sandstone	✓		
		Corallian Group	limestone and sandstone with siltstone and mudstone			
		Middle Jurassic rocks undifferentiated (including Kellaways/Oxford Clay Formations)	mudstone and sandstone	✓		
		Great and Inferior Oolite Groups	Limestone, with siltstone, mudstone and sandstone			
		Lias Group	mudstone with limestone and siltstone	✓		
	Triassic (201.3 – 251.9)	Mercia Mudstone Group (including Sidmouth Mudstone Formation)	mudstone, siltstone and sandstone with evaporite deposits of anhydrite, gypsum and halite	✓		
		Sherwood Sandstone Group	sandstone with siltstone, mudstone, conglomerate			
	Permian (251.9 – 298.9)	Cumbrian Coast and Appleby Groups	mudstone and siltstone with sandstone, conglomerate and evaporites			
Older sedimentary and related rocks	Carboniferous (298.9 – 358.9)	Warwickshire Group	mudstone and sandstone with limestone and coal			
		Pennine/South Wales Coal Measures Group	sandstone, siltstone, mudstone and coal			
		Millstone Grit/Marros Group	mudstone and sandstone with siltstone and conglomerate			
		Craven Group	mudstone and limestone with sandstone and siltstone			
		Carboniferous Limestone Supergroup	limestones with sandstone and mudstone			
	Devonian to Silurian (358.9 – 443.8)	Upper Old Red Sandstone Group	sandstone and conglomerate with siltstone and mudstone			
		Lower Old Red Sandstone Group including Traeth Bach Formation	weakly metamorphosed sandstone, conglomerate and siltstone		✓	

[2] 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 2 Cont'd

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Basement Rocks	Silurian (419.2 – 443.8)	Pridoli Groupo	siltstone with conglomerate, sandstone and limestone		✓	
		Ludlow,Wenlock and Llandovery Groups	slaty mudstone and slate with sandstone		✓	
	Ordovician (443.8 – 485.4)	Ordovician metasediments, not differentiated including Ashgill, Caradoc, Llanvirn and Arenig Groups)	slaty mudstone and slate with sandstone		✓	
		Ordovician metavolcanic rocks and sills, not differentiated	weakly metamorphosed lavas and pyroclastic rocks		✓	
		Ordovician minor igneous intrusions, not differentiated	weakly metamorphosed granitic rocks		✓	
	Ordovician to Cambrian (443.8 – 541.0)	Cambrian to Tremadoc metasediments, undifferentiated	weakly metamorphosed mudstones with siltstone and sandstone		✓	
		Monian Supergroup	metamorphosed sedimentary and volcanic rocks		✓	
	Precambrian (older than 541.0)	Neoproterozoic volcanic rocks	metamorphosed tuffs, breccias, lavas		✓	
		Precambrian basement rocks, not differentiated	metamorphosed sedimentary and igneous rocks		✓	

Figure 3 Generalised geological map showing the distribution of rock units in Wales. The inset shows the extent of the country 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.



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 4 Schematic cross-section west to east through North Wales. 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.

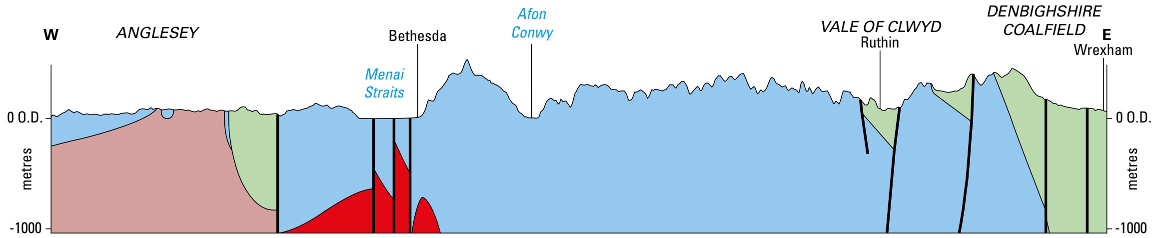


Figure 5 Schematic cross-section north-west to south-east through Central Wales. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types.

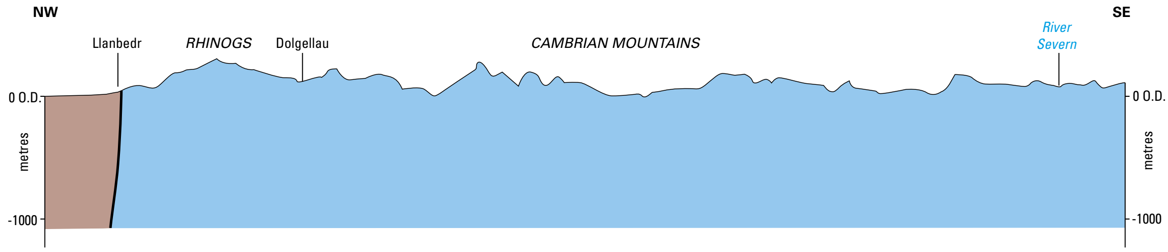


Figure 6 Schematic cross-section north-west to south-east through South Wales. Line of section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. See Figure 2 for the key to the rock types.

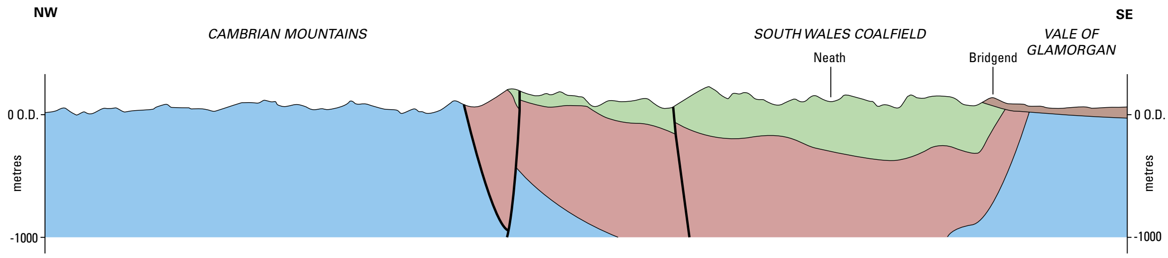


Figure 7a The areas of Wales where any of the 3 Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

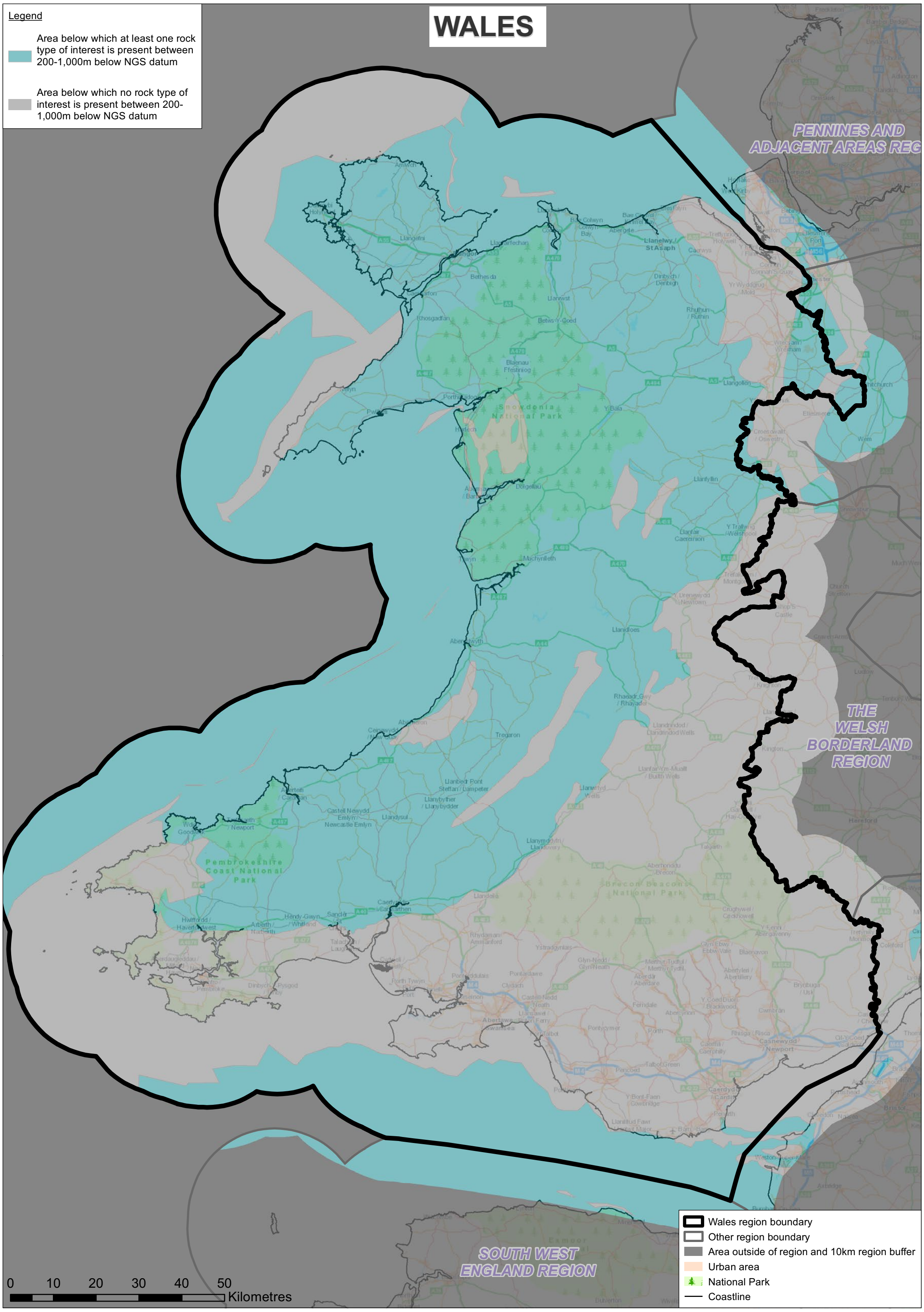


Figure 7b The areas of Wales where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

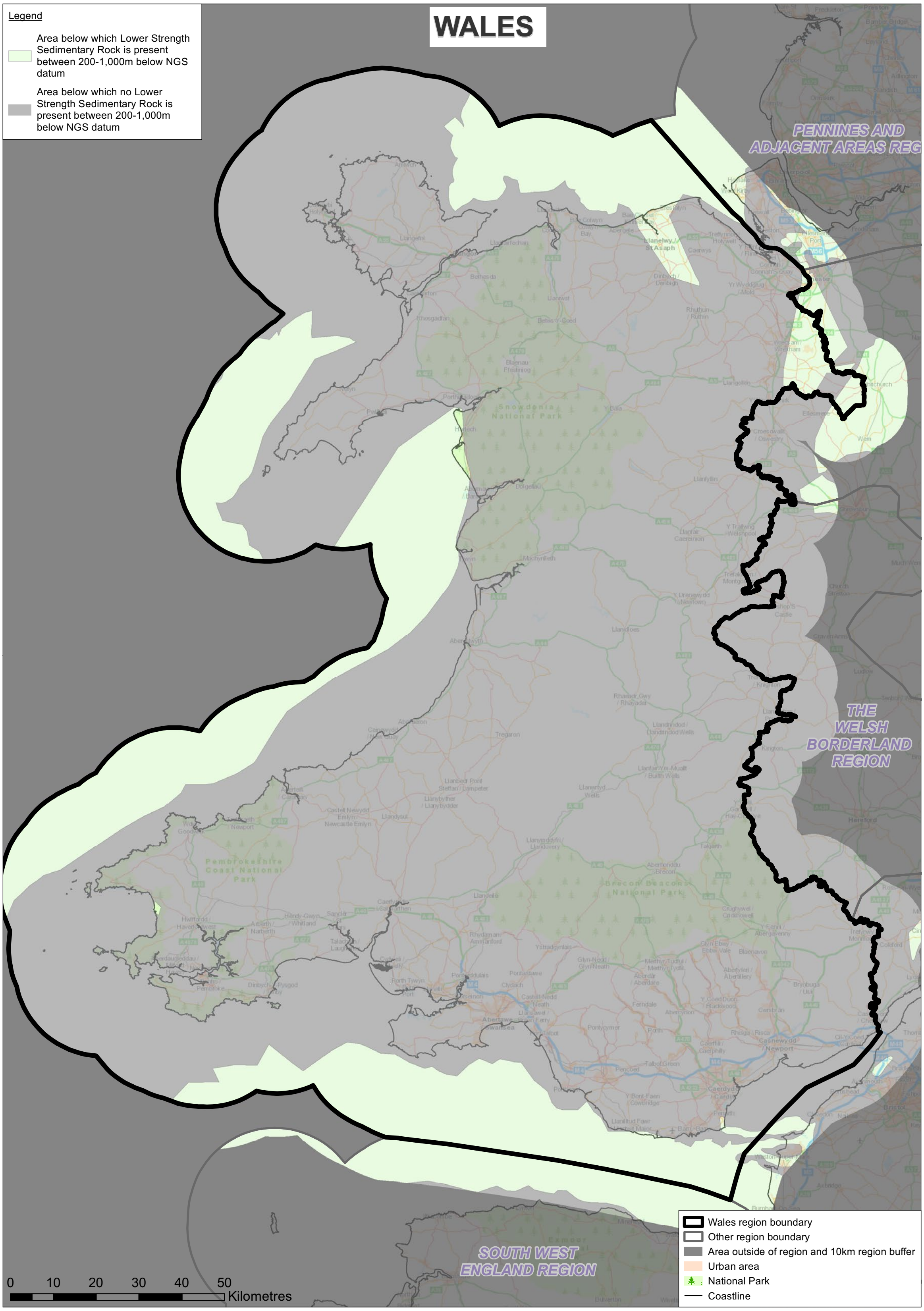


Figure 7c The areas of Wales where Higher Strength Rock Types of Interest are present between 200 and 1,000 m below NGS datum

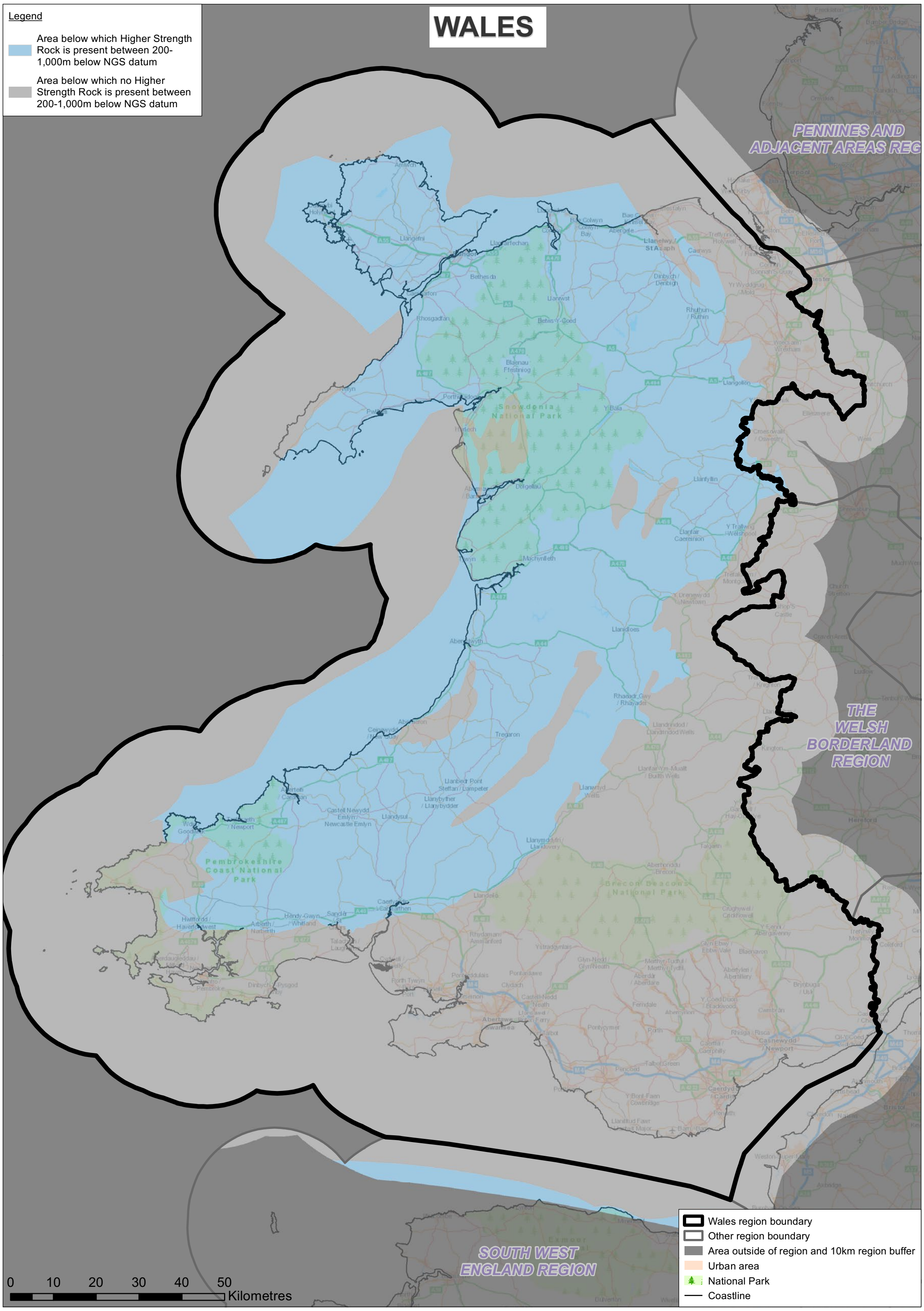


Figure 7d The areas of Wales where Evaporite Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

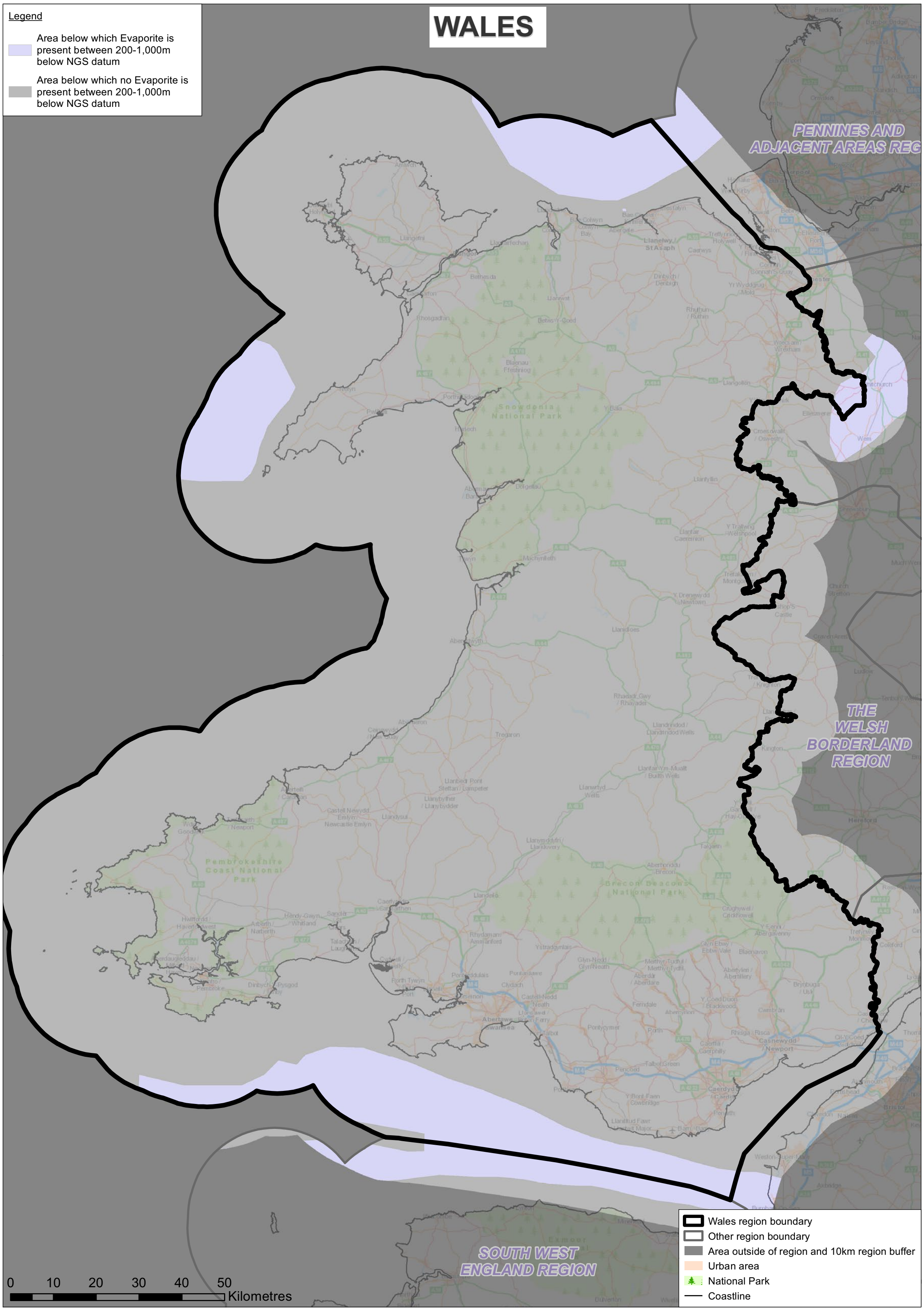


Figure 8 Major faults and areas of folding in Wales.

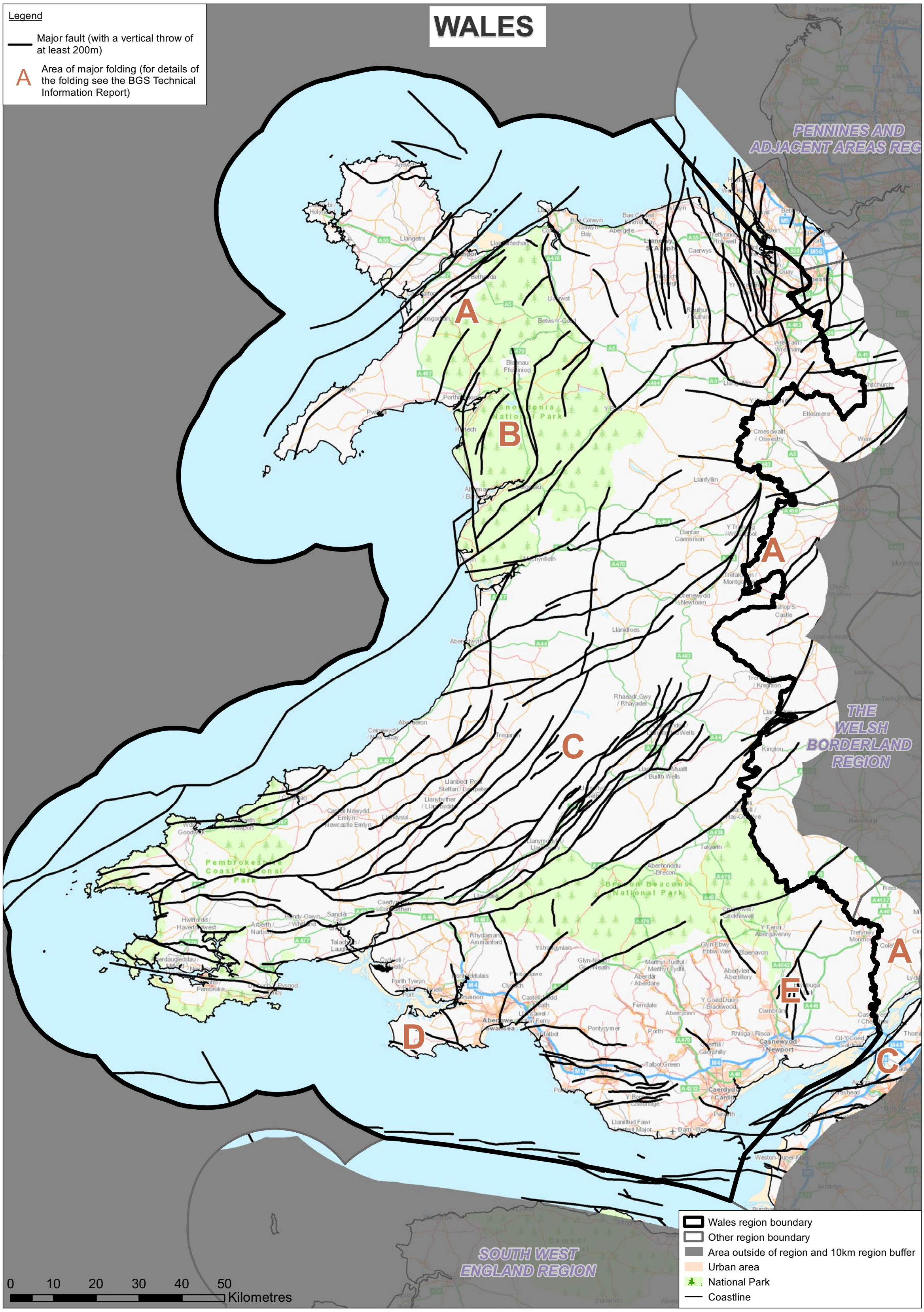


Figure 9a Areas of Wales with metal and vein mineral mines present below 100m and thermal springs.

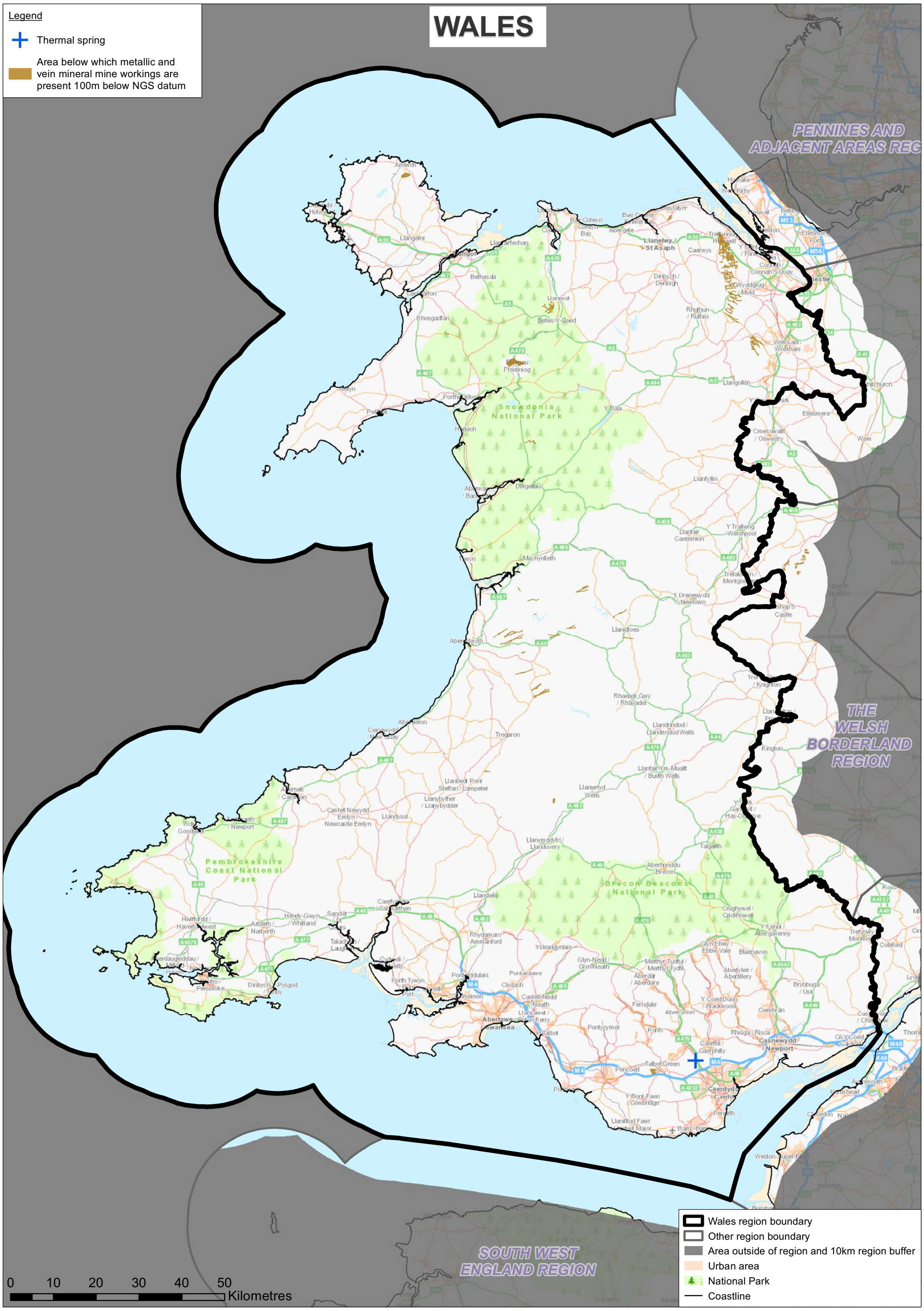


Figure 9b Areas of Wales with coal mines more than 100m deep and Coal Authority Licence Areas.

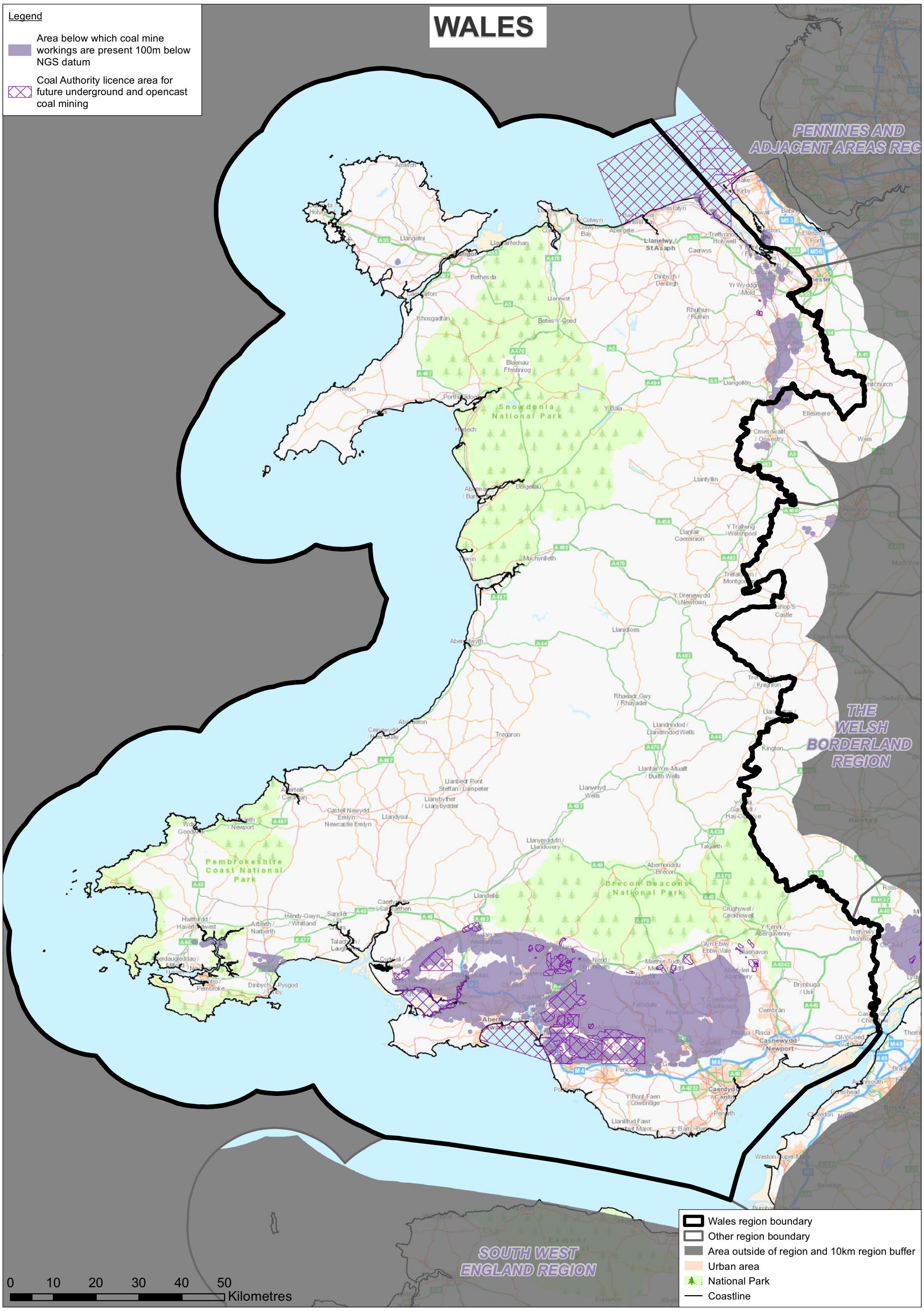


Figure 9c Areas of Wales with oil and gas fields and Petroleum Exploration and Development Licences.

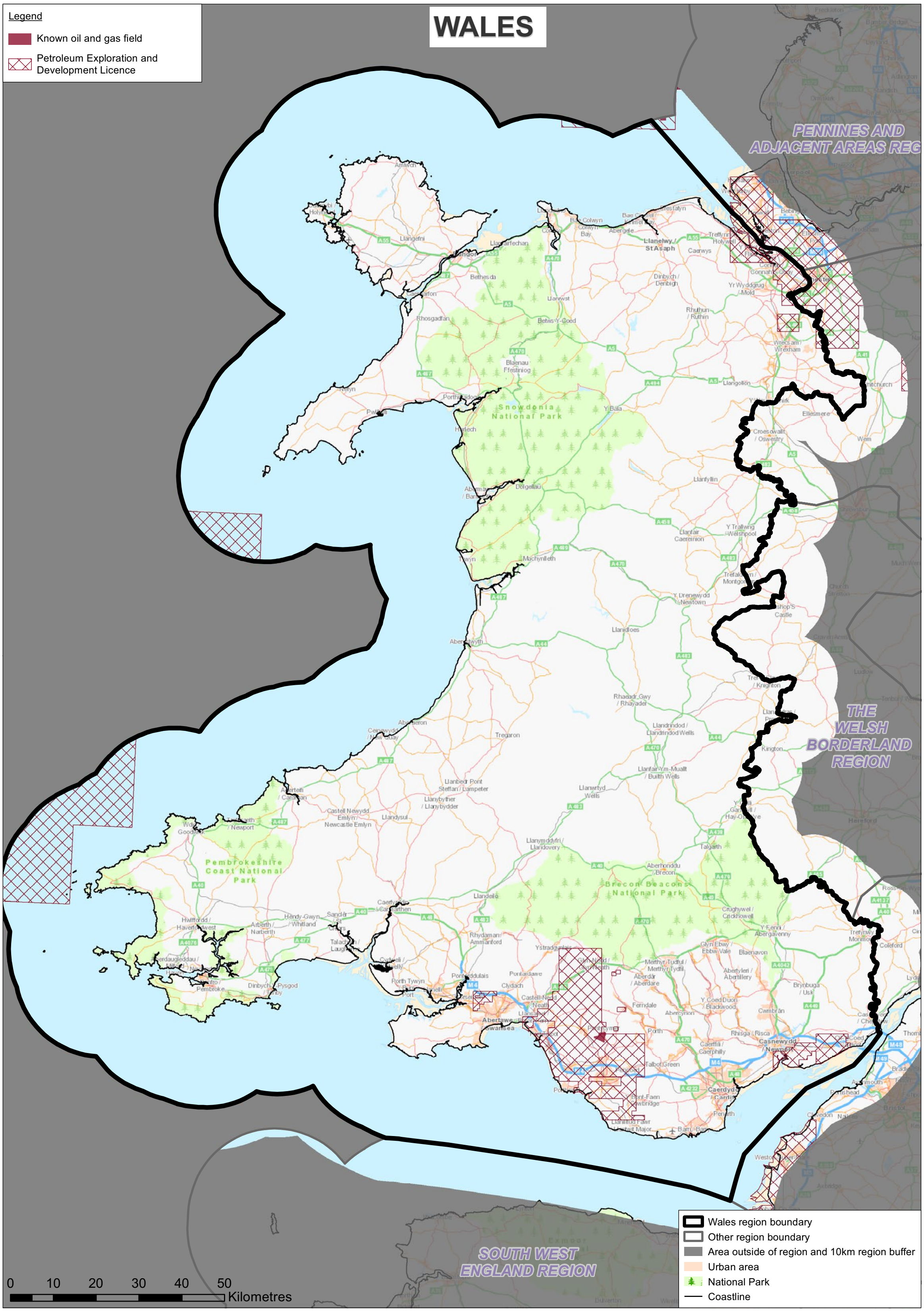


Figure 9d Areas of Wales with historical mining less than 100m deep and known mineral deposits.

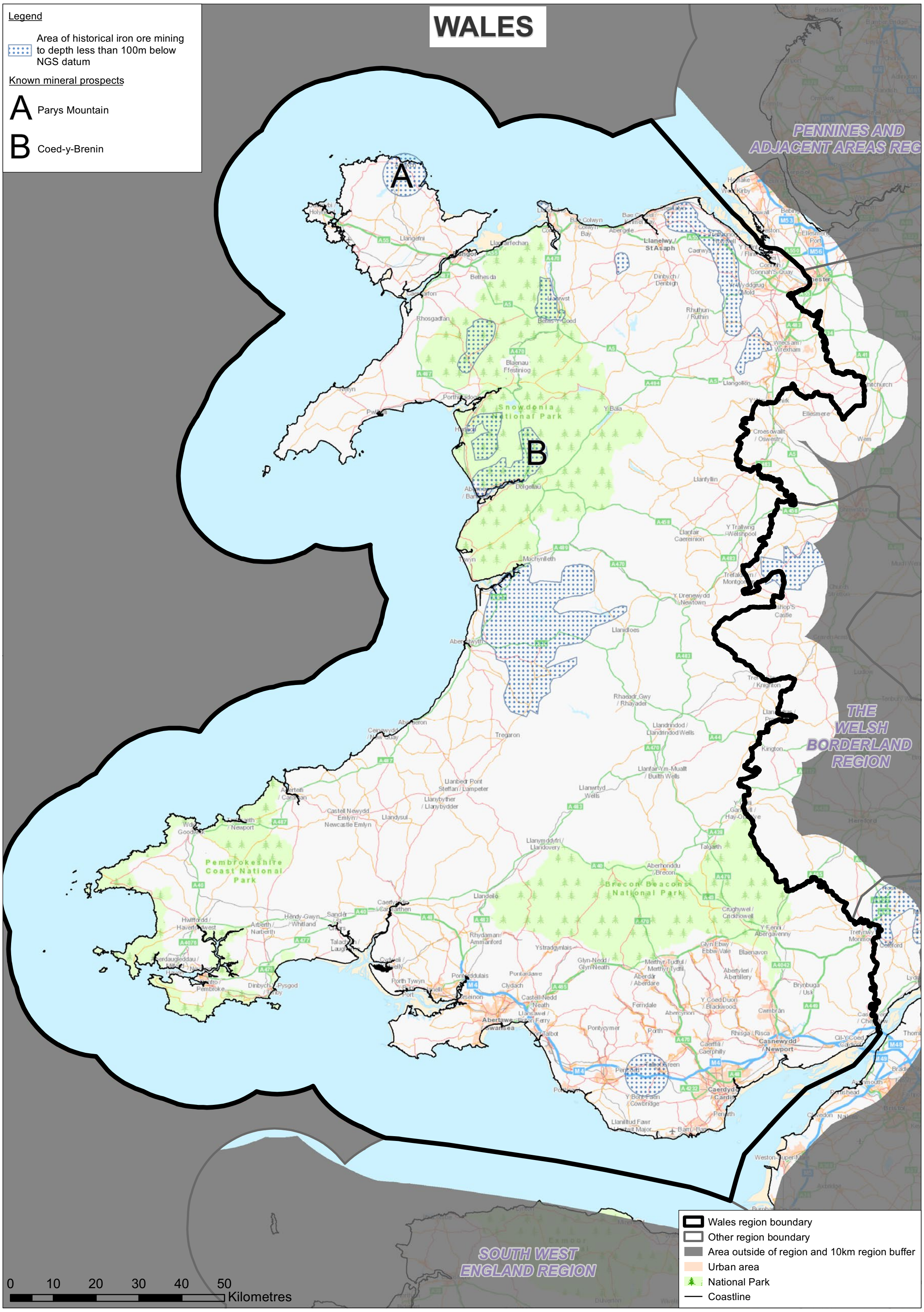
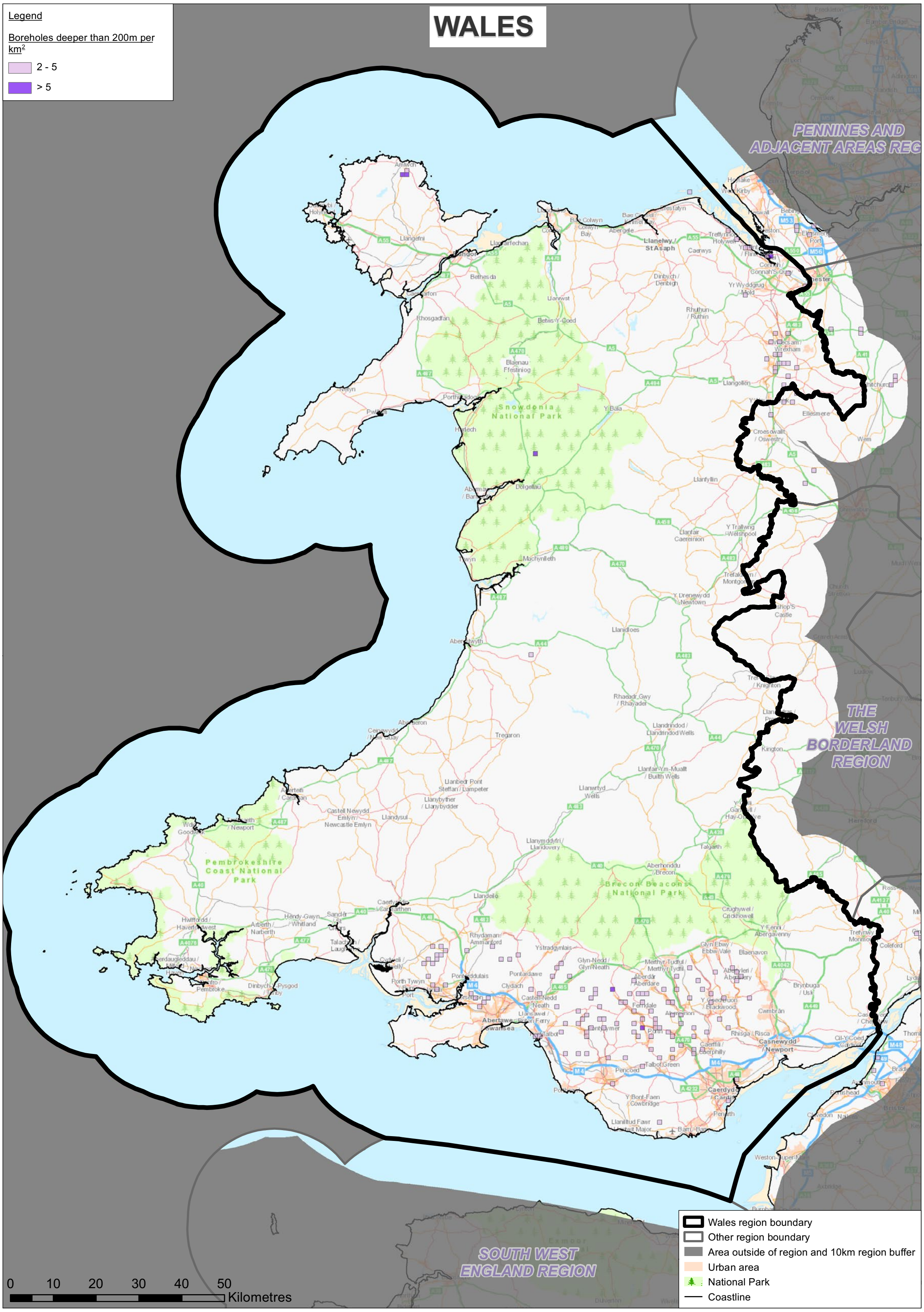


Figure 10 Areas of Wales with concentrations of deep exploration boreholes.



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.

Breccia
A type of sedimentary rock made up of large angular clasts. The space in between the fragments is filled with a fine-grained background 'matrix' which cements the larger clasts together.

Coal bed methane

Natural gas trapped in underground coal seams and extracted using boreholes without the need for a coal mine.

Coal bed methane
Natural gas trapped in underground coal seams and extracted using boreholes without the need for a coal mine.

Conglomerate
Coarse sedimentary rock comprising large, rounded pebbles, and even boulders, set in a finer grained background, or matrix. Conglomerates accumulate in land and submarine environments, often at the margins of fault-bounded basins where fast-flowing rivers enter low-lying valleys.

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.

Epicentre
The point on the surface of the Earth above the focus of an earthquake.

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.

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'.

Hypocentre
The point underground where the earthquake occurs.

Lava flow
A mass of flowing or solidified lava. After cooling and solidification, lava flows often form distinctive topographical features.

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.

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.

Schist
Recrystallized metamorphic rocks with a distinctive texture caused by the parallel alignment of tiny crystals of mica. As a result, schists are characteristically sheet-like, rather like the pages of a telephone directory.

Sediment
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).

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.

Shale
A very fine-grained and strongly layered sedimentary rock in which the grains are not visible to the naked eye. Consists of clay grains and tiny fragments of other minerals such as quartz and mica.

Shale gas
Gas that is naturally generated and trapped within shales that contain a high amount of organic material. Shale gas can be extracted for use as a fuel in heating or power generation by a technique known as hydraulic fracturing or 'fracking'.

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

Tuff
Fine-grained rock formed from compacted ash ejected during explosive volcanic eruptions.

Variscan
An episode of mountain-building during the Carboniferous period that led to deformation of the basement rocks of much of the southern UK.

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