

The Welsh Borderland

REGIONAL GEOLOGY



Contents

- 1** Introduction
 - The Welsh Borderland: summary of the regional geology
 - Available information for this region
- 2** Rock type
 - Younger sedimentary rock
 - Older sedimentary rock
 - Basement rocks
- 3** Rock structure
- 4** Groundwater
 - Resources
- 5** Natural processes
 - Further information
- 6 - 11** Figures
- 12 - 13** Glossary

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

The Welsh Borderland region comprises southern Shropshire, the western half of Herefordshire and Worcestershire, and a small area of northern Gloucestershire and extends along the English side of the border with Wales from north of Shrewsbury to near Ross-on-Wye in the south.

To present the conclusions of our work in a concise and accessible way, for most of the regions we have selected subregions with broadly similar geological attributes relevant to the safety of a GDF. For the Welsh Borderland, the [geological attributes](#) relevant to the long term safety of a GDF do not vary significantly, so no subregions have been defined and it is treated as a single region ([Figure 1](#)). 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.

The Welsh Borderland: 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

Although the surface geology of this region has been intensely studied by geologists, there is relatively little information from depths of more than a few tens to hundreds of metres. Only 3 [boreholes](#) extend below 1,000m. [Geophysical investigations](#), which include studies of the Earth's gravity and magnetic fields and [seismic surveys](#), are sparse in this 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 to show the oldest 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 major rock units occur at the surface. [Figure 4](#) presents a schematic vertical cross-section 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](#). [Figure 5](#) shows where in the region there are likely to be LSSR with potential for the development of a GDF within the [depth range of interest](#). There are no potential HSR or Evaporite host rocks in this region.

Younger sedimentary rocks

The youngest rocks occurring in the depth range of interest for screening are [sedimentary](#) rocks of Triassic to Permian age (approx. 200 – 300 million years old). These are referred to here as the younger sedimentary rocks and comprise sandstones, siltstones and mudstones. The Mercia Mudstone Group in this rock sequence contains thick mudstones and is likely to behave as a [LSSR](#). The Mercia Mudstone Group occurs at the surface in the vicinity of Worcester in the east of the region.

Older sedimentary rocks

Older sedimentary rocks of Carboniferous to upper Silurian age (approx. 300 to 425 million years old) are present below the [younger sedimentary rocks](#). The Warwickshire and Pennine Coal Measures Groups, which are dominated by mudrocks and sandstone and sometimes include coals, are present in the north of the region around Shrewsbury. The underlying Upper and Lower Old Red Sandstone Groups, mainly comprising sandstones, siltstones and [conglomerates](#), and the Raglan Mudstone Formation are widespread across the region.

Basement rocks

Beneath the Raglan Mudstone Formation is a wide range of older rocks referred to here as [basement](#) rocks (approx. 425 to 700 million years old). The older Silurian sedimentary rocks (approximately 425 to 445 million years old), comprising mudrocks, sandstones and limestones, have not been [folded](#) and [metamorphosed](#) in this region as they have in other regions such as Wales. Instead they have experienced similar episodes of deformation to the [older sedimentary rocks](#) described above and therefore share a similar range of properties.

The underlying Ordovician and Cambrian rocks (approx. 445 - 540 million years old) include a range of sedimentary rock types, dominated by [shales](#) but with siltstones, sandstones and rare limestones. There is also a range of volcanic rocks present including [lava flows](#), [tuffs](#) and small [igneous](#) intrusions, mainly of [basaltic](#) or andesitic composition.



The oldest basement rocks present in the region are of late Precambrian age (older than approximately 540 million years old). These rocks are only present in the [depth range of interest](#) where they have been uplifted as relatively small bodies in major structural features, notably the Malvern Fault system in the south-east of the region, and the Church Stretton Fault and Pontesford Lineament to the north-west. The Precambrian rocks are diverse and include sedimentary, [metamorphic](#) and igneous rock types.

Rock structure

The major [faults](#) and [folding](#) in the region are shown in [Figure 6](#). The [basement](#) and [older sedimentary rocks](#) are more extensively faulted and folded than the [younger sedimentary rocks](#). North-east to south-west [faults](#) are part of the Welsh Borderland Fault System, including the Church Stretton Fault Complex and the broadly parallel faults to the north-west. These faults result in the exposure of a variety of Precambrian rocks at the surface forming the Long Mynd and some other prominent hills and have folding associated with them. The other major fault system in the region is the north – south aligned Malvern Fault zone, which likewise gives rise to a series of hills of older igneous and metamorphic rocks brought to the surface by the faulting.

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.

In this region the basement mudrocks have not been intensely folded and metamorphosed to form slates like those further west in Wales, although they have been sufficiently [compacted](#) to be described as shales.



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. The region contains several [principal aquifers](#). They include the Sherwood Sandstone which only occurs in the far north of the region, in an extension of the major aquifer of the Cheshire Basin, and in the east, where the Worcester basin extends a small distance into this region. In addition, the Carboniferous rocks, the Lower and Upper Old Red Sandstone Groups and certain layers in the Raglan Mudstone Formation, are also widely used as sources of groundwater in the region.

Where [LSSR](#) layers are present they are likely to act as [barriers to groundwater movement](#) between the aquifers and between deep and shallow groundwater, even where they are not thick enough to host a GDF. In addition to the Mercia Mudstone and Warwickshire Groups LSSR, some of the basement rocks, including the Precambrian igneous and sedimentary rocks may also act as barriers to groundwater movement. Mining for coal and for metal ores in parts of the region is likely to have changed the original patterns of water movement and shallow groundwater may circulate to greater depths within the depth range of interest now than it did before mining. There are no concentrations of [deep exploration boreholes](#) in this subregion or [thermal springs](#) to suggest rapid flow of deep groundwater to the surface.

Resources

A range of resources have been exploited in this region. The areas where metal and [vein](#) mineral mines are present below 100m are shown in [Figure 7a](#). The areas where coal mines are present below 100m are shown in [Figure 7b](#). Areas of historic lead, zinc and barite mining shallower than 100m are shown in [Figure 7c](#).

The main area of coal mining was the Shrewsbury Coalfield, south-west of Shrewsbury, where mining extended to a maximum depth of about 150m. The region also includes small coal mining areas in the Wyre Forest in the east and around Newent in the south but there are no current mining activities.

The Shropshire orefield in the north-west of the region was a source of lead from Roman times up to the mid-20th century, with zinc and latterly barytes also important resources ([Figure 7c](#)). Most of the mining was shallower beyond 100m below the surface, but a number of mines extended deeper than this and the deepest was over 500m ([Figure 7a](#)).

There has been no [hydrocarbon](#) production in the region, apart from historic shallow mining for tar at Coalport, just south of Telford, and there are currently no [Petroleum Exploration and Development Licences](#) or [Coal Authority Licence Areas](#).



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 has experienced a number of small earthquakes for which there are historical records, with 4 earthquakes of magnitude 4Mw or greater in the past 200 years. The largest of these, the magnitude 5.0Mw Hereford earthquake of 1896, caused local damage to buildings and chimneys. The 1990 Bishop's Castle earthquake, magnitude 4.8Mw, was felt throughout Wales and much of England but caused only minor damage.

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.

Much of the region was affected by the [Anglian](#) and [Devensian](#) continental-scale glaciation during the [Pleistocene](#) epoch, and during the peak of glaciation, both highland valley glaciers and lowland lobes extended into this region. The precise siting and design of a GDF would need to consider the potential impacts of glaciation and permafrost during future highland, lowland and continental-scale glaciations. These may include increased [erosion](#) and changes to groundwater movement.

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](#). Note that the BGS Welsh Borderland region extends into adjacent parts of Wales; these have been treated as part of Wales for screening purposes. The [BGS Regional Guide](#) also provides details about many of the sources of information underpinning the [TIR](#).



Figure 1 The Welsh Borderland region as defined for the purpose of National Geological Screening.

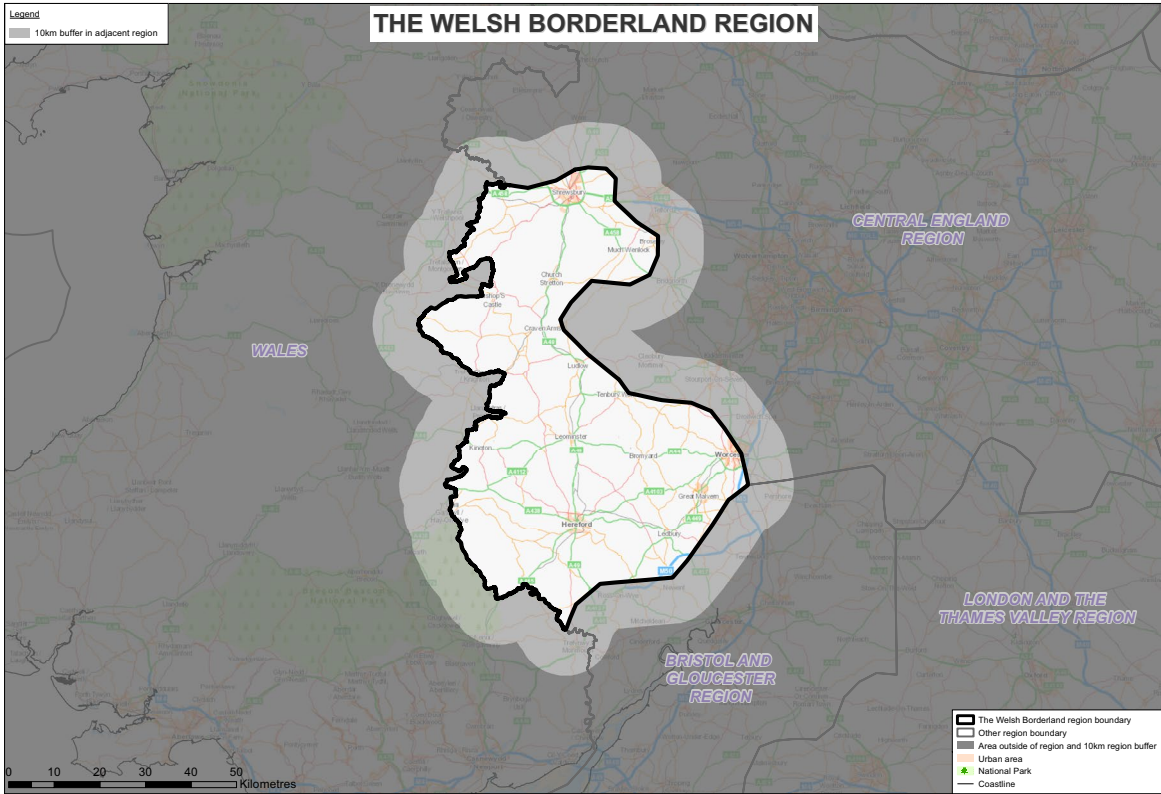




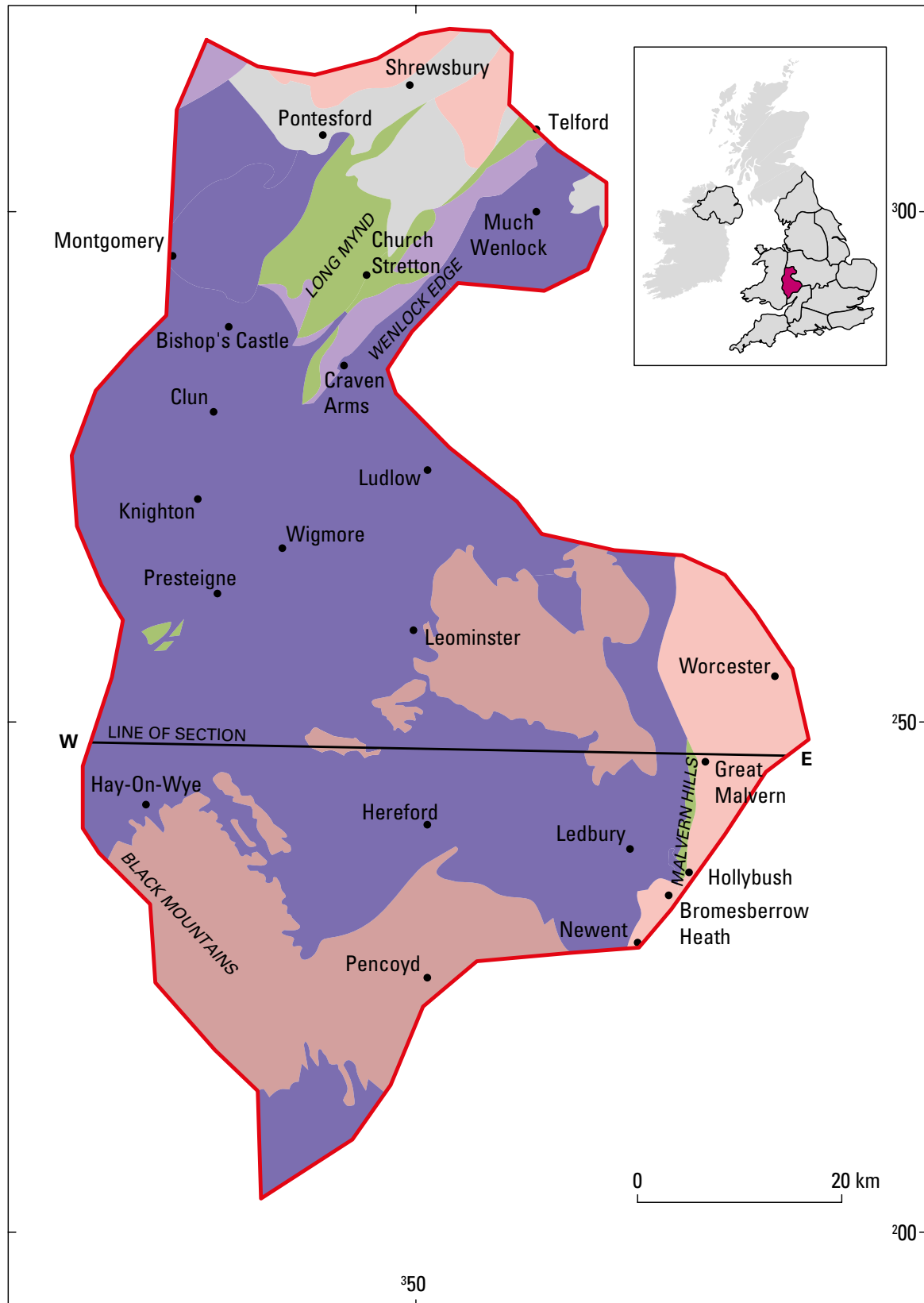
Figure 2 Table illustrating the sequence of the major rock units present in the Welsh Borderland region and their possible significance for the siting of a GDF.

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Younger Sedimentary Rocks	Triassic (201.3 – 251.9)	Penarth Group	Not applicable as not within the depth range of interest	Not applicable as not within the depth range of interest		
		Mercia Mudstone Group	mudstone with siltstone and evaporite deposits of anhydrite, gypsum and halite	✓		
		Sherwood Sandstone Group	sandstone, siltstone and mudstone			
	Permian (251.9 – 298.9)	New Red Sandstone Supergroup	sandstone			
		Undifferentiated Permian rocks	sandstone and conglomerate			
Older Sedimentary and Related Rocks	Carboniferous (298.9 – 358.9)	Warwickshire Group	siltstone and sandstone with mudstone	✓		
		Pennine (north) and South Wales (south) Coal Measures Groups	mudstone, sandstone, siltstone and coal			
		Marros and Millstone Grit Groups	mudstone, sandstone, siltstone and coal			
		Carboniferous Limestone Supergroup	limestone with sandstone and mudstone			
	Devonian to Silurian (358.9 – 443.8)	Upper Old Red Sandstone Group	sandstone, conglomerate, siltstone, mudstone			
		Lower Old Red Sandstone Group including	sandstone, conglomerate, siltstone, mudstone			
		Raglan Mudstone Formation	mudstone and siltstone			
Basement	Silurian (419.2 – 443.8)	Pridoli, Ludlow, Wenlock and Llandovery Groups	mudstone, siltstone and sandstone			
	Ordovician (443.8 – 485.4)	Ordovician rocks, not differentiated including Caradoc, Llanvirn and Arenig Groups)	mudstone, siltstone and sandstone			
		Ordovician volcanic rocks and minor igneous intrusions	tuff			
	Cambrian (485.4 – 541.0)	Cambrian to Tremadoc Group rocks, not differentiated	mudstone, siltstone and sandstone			
	Precambrian (older than 541.0)	Neoproterozoic rocks, not differentiated including East Malvern Complex	weakly metamorphosed sedimentary and igneous rocks, schists			

NB In this region, older Silurian rocks occur directly beneath the Raglan Mudstone; deposition was continuous and they have experienced a similar geological history, without the deformation and metamorphism experienced by rocks of the same age to the west in much of Wales. For simplicity and comparability with other regions, Silurian and older rocks are designated as part of the basement, except for the Raglan Mudstone.



Figure 3 Generalised geological map showing the distribution of rock units in the Welsh Borderland region. The inset shows the extent of the region in the UK. The bold black line gives the location of the cross-section shown in Figure 4. 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 4 Schematic cross-section of the Welsh Borderland region along the line 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.

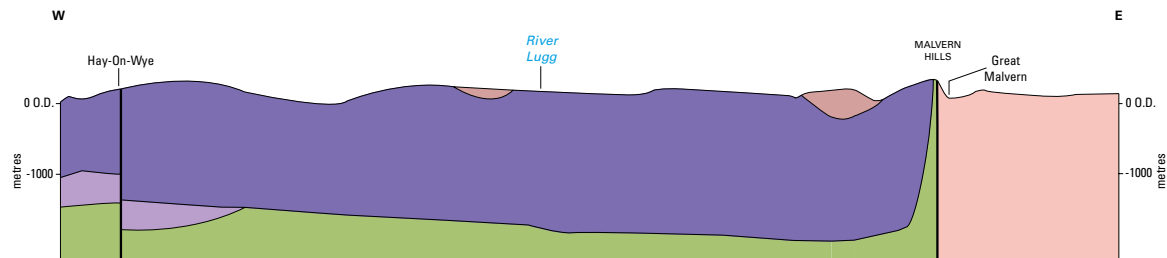


Figure 5 The areas of the Welsh Borderland region where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000m below NGS datum.

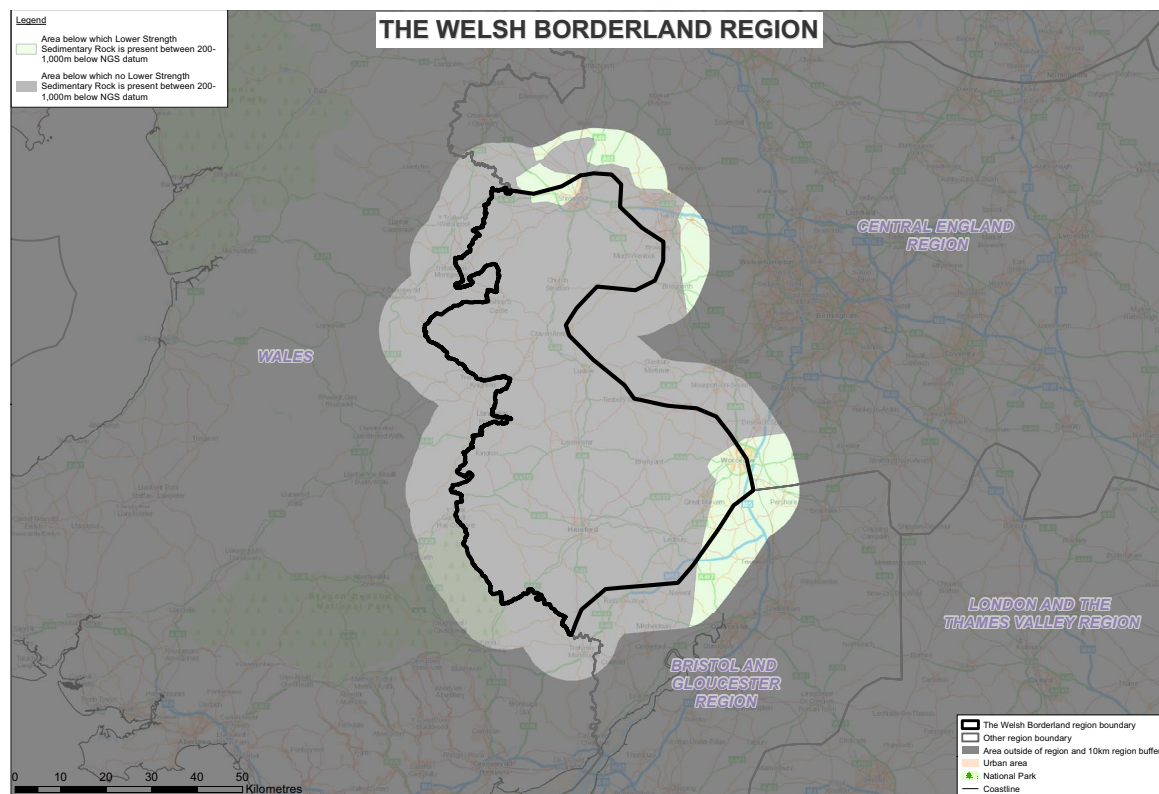




Figure 6 The areas of the Welsh Borderland region where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000m below NGS datum.

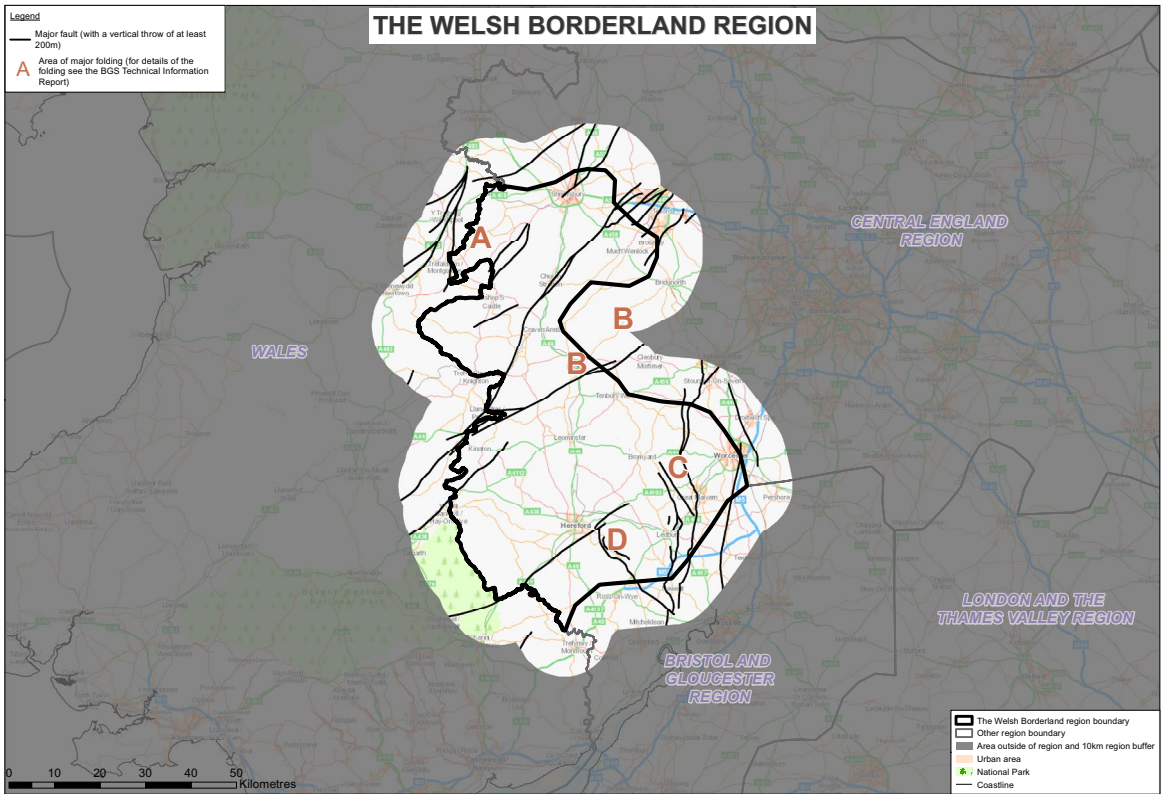


Figure 7a Areas of the Welsh Borderland region with metal and vein mineral mines present below 100m.

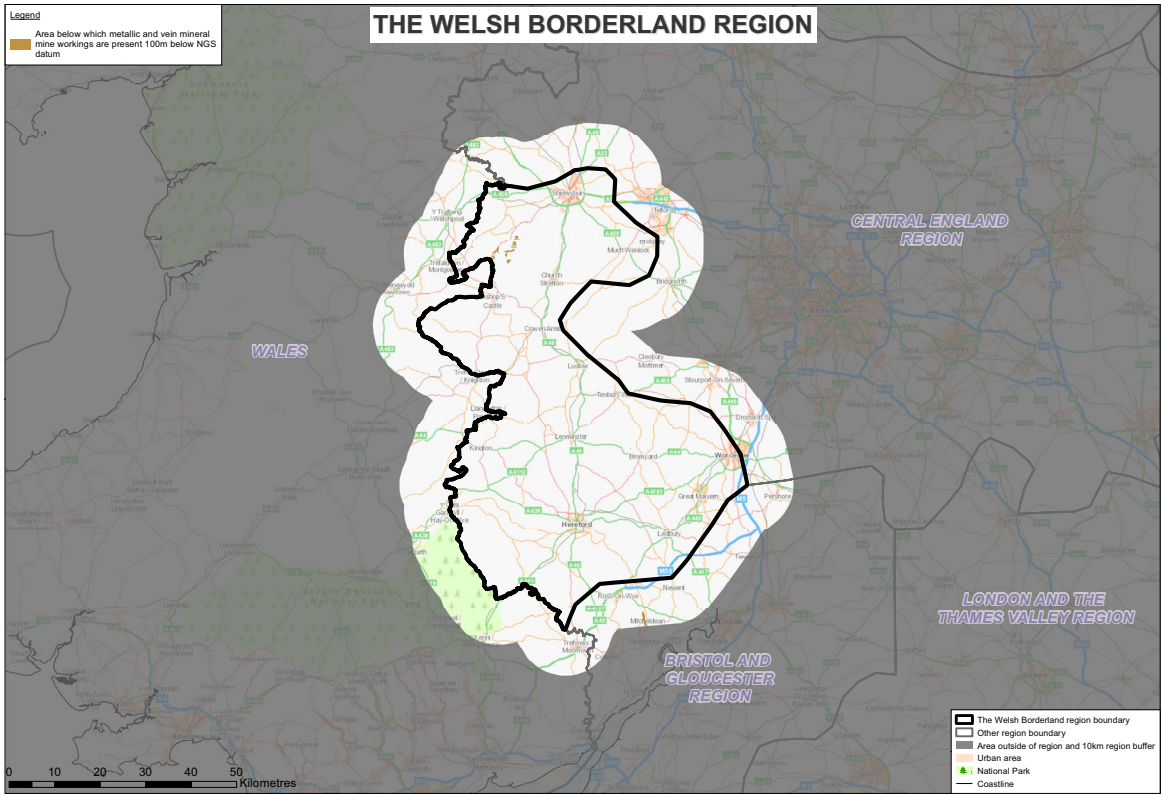




Figure 7b Areas of the Welsh Borderland region with coal mines present below 100m.

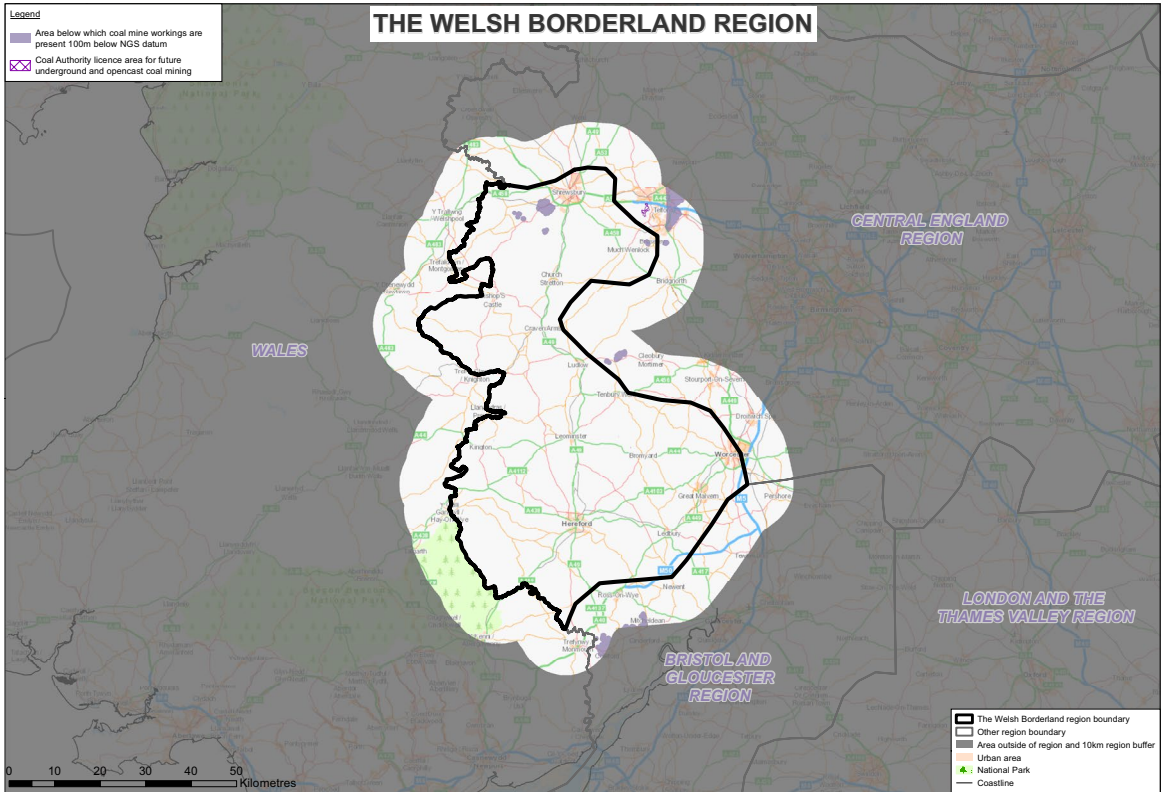
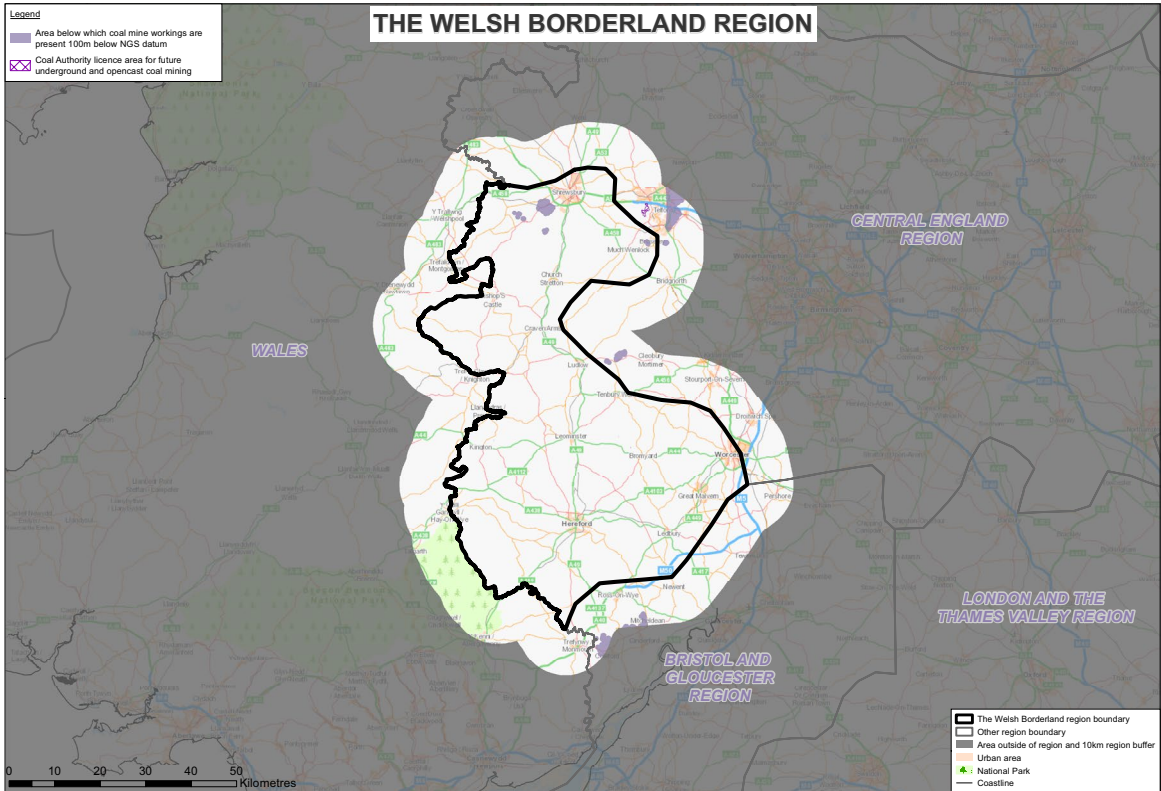


Figure 7c Areas of the Welsh Borderland region with historical metal and vein mineral mines less than 100m deep.





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.

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.

Basalt

Dense, dark-coloured lava rich in iron and magnesium. Forms during non-explosive eruptions of shield volcanoes, often in oceanic islands such as Hawaii.

Compacted

The action of squeezing as sediments become more deeply buried. Like wringing a sponge, compaction leads to loss of pore water and reduction of pore spaces between rock grains.

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.

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.

Fault

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

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.

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.



Metamorphic/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.

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.

Tuff

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

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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