British Geological Survey

The geothermal potential of early Carboniferous limestone in the UK

Summary

- The thermal springs in Bath, Bristol, the Taff Valley and the Peak District are formed where early Carboniferous limestone rocks come to surface
- Where the limestone is buried in the subsurface, groundwater flowing through it creates potential for geothermal energy in the UK
- The groundwater could be exploited via geothermal doublets, for direct-use heat, or heat pumps for heating, cooling and thermal storage; geothermal energy can also be used in conjunction with district heating networks
- Areas of potential summarised here from legacy reports are:
  - East Midlands, northern West Midlands and northern England (northern province)
  - Mendip Hills and South Wales (southern province)
  - Northern Ireland
- Many of these areas are close to urban settlements and therefore heat demand
- Geothermal potential is controlled by the ability of groundwater to flow through the rock and is significantly affected by processes that create porosity and permeability some time after the rock was deposited (secondary porosity)

Background

The potential for utilising geothermal energy in the UK, which was first comprehensively assessed in the 1980s (Downing and Gray, 1986), is of increasing importance for heat decarbonisation and increased energy security. While the geological and tectonic setting of the UK precludes high-temperature exploitation, low- to moderate-temperature geothermal sources have been identified for heat (and, in a more limited way, power) utilisation. The early Carboniferous limestone (between 359 and 323 million years old) is one of these potential deep geothermal sources.

The potential resource

In the UK, the early Carboniferous limestone is present in a northern province, stretching from Wrexham to the Humber Estuary, and a southern province, from the Bristol Channel to Kent and Medway. The rocks either occur at surface outcrop or are concealed in sedimentary basins at depths of up to 5500 m (Figure 1 and Figure 2). The warm springs in Bath and Bristol, the Taff Valley and the Peak District, which issue thermal waters at temperatures between 16 and 48˚C from the early Carboniferous limestone, are manifestations of groundwater that has been heated as it flows through the rocks at depth.

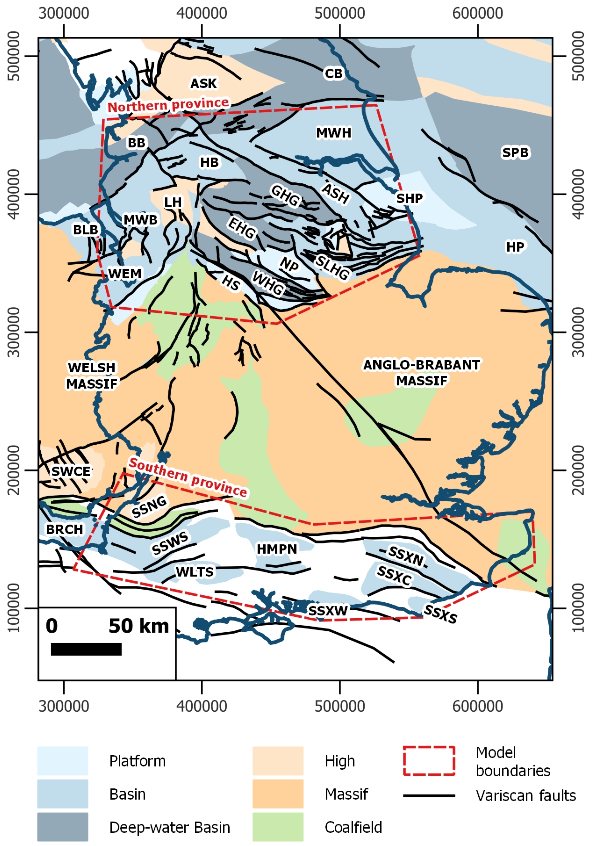

Figure 1 Map of early Carboniferous basins and highs, showing the location of the northern and southern areas of interest. ASH: Askern–Spittal High; ASK: Askrigg Block; BB: Bowland Basin; BRCH: Bristol Channel; BLB: Blacon Basin and Bristol Channel Basin; CB: Cleveland Basin; EHG: Edale Half-graben; GHG: Gainsborough Half-graben; HB: Huddersfield Basin; HMPC: central Hampshire subcrop; HMPN: north Hampshire subcrop; HP: Hewett Platform; HS: Hathern Shelf; LH: Lymm High; MWB: Manchester–Winsford Basin; MWH: Market Weighton High; NL: Newark Low; NP: Nottingham Platform; SHP: South Humber Platform; SLHG: Sleaford Half-graben; SPB: Sole Pit Basin; SSNG: north Somerset and Gloucestershire subcrop; SSWS: south Somerset and north Wiltshire subcrop; SSXC: central Sussex subcrop; SSXN: north Sussex subcrop; SSXW: west Sussex subcrop; SSXS: south Sussex subcrop; WEM: Wem Subbasin; WHG: Widmerpool Half-graben; WLTS: South Wiltshire Basin. Reproduced and modified from Jones et al. (2023), after Pharoah et al. (2021). British Geological Survey © UKRI 2025. Published by Elsevier Ltd.

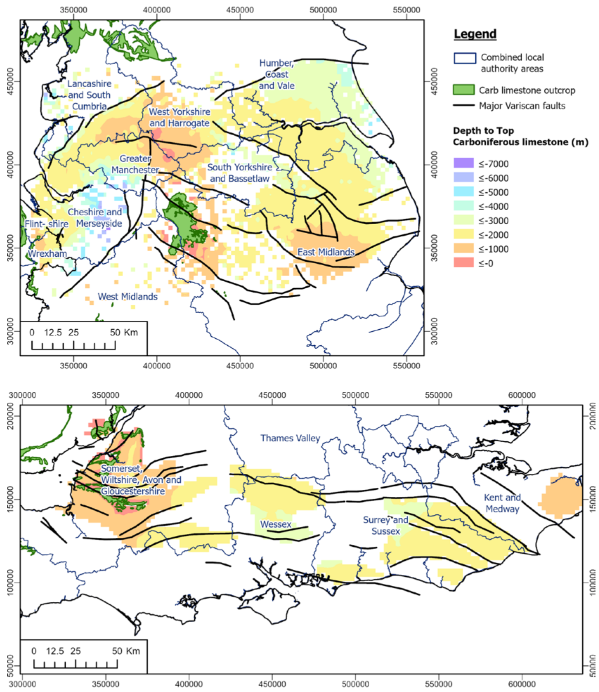

Figure 2 Maps of the northern and southern provinces showing depth to top early Carboniferous limestone overlain with its outcrop, major Variscan faults and combined local authority areas. Reproduced from Jones et al. (2023) Published by Elsevier Ltd. British Geological Survey © UKRI 2023.

How does groundwater flow occur?

Although the early Carboniferous limestone is generally hard and compact (low porosity and low permeability), the ability of the rock to transmit groundwater (transmissivity) is significantly increased by processes such as karstification, fracturing, dolomitisation and evaporite dissolution.

Karstification

Karstification refers to the process where soluble rocks such as limestone are dissolved by atmospheric water, resulting in the formation of extensive subsurface drainage systems and caves. In the UK, there is abundant evidence for karst formation both during the Carboniferous (palaeokarst) and subsequently, due to uplift of carbonate platforms into the contemporary near-surface zone. In many cases, karstification is associated with the development of palaeosol (fossil soil) horizons and discontinuities within the rock strata. Those geological markers can be used to identify zones where karstification may have enhanced the permeability of the rock.

Fractures and fissures

Fractures and fissures provide preferential pathways for groundwater flow. They can be enlarged by dissolution, especially in soluble rocks like limestone that are susceptible to dissolution in even mildly acidic water. Flow depends on fracture size: the early Carboniferous limestone is well-fractured (largely solution enlarged) and the fracture size increases proportionally to the age of the aquifer.

Tectonic fractures may act as high or low permeability zones, while joints enhance permeability. Flow velocities can be very rapid but depend on the presence of interconnected conduit systems (Allen et al., 1997).

Dolomitisation

Dolomitisation refers to the process of the conversion of calcite to dolomite by the substitution of magnesium cations for calcium cations within the mineral structure. This results in a volume reduction of up to 12 per cent and the formation of secondary porosity within the rock matrix. Dolomitisation is linked to the downward passage of brines from overlying formations, or the upward passage of mineralising solutions along fractures and fault planes.

Evaporite dissolution

Dissolution of evaporites within the early Carboniferous limestone has created voids and spaces that both enhance the capability of the rock to store water (secondary porosity) and permit water movement (permeability). The early Carboniferous limestone contains different evaporite minerals such as gypsum, anhydrite and halite (rock salt) as a result of hypersalinity in the depositional environment and they are particularly prominent in the earliest Carboniferous (Tournaisian) strata. These minerals are easily dissolved and may be present at higher stratigraphic levels as well.

Regional geothermal potential

Northern province

East Midlands

The early Carboniferous limestone was deposited across a wide shelf and is well known from its outcrop in the Peak District and from the margins of subsurface basins (Figure 1 and Figure 2). Thermal springs of meteoric origin occur at Buxton (27.7°C), Matlock (20.0°C), Bakewell (15.5°C) and Stoney Middleton (17.7°C) in the Peak District. Of numerous boreholes proving the top of the limestone in this region, only six penetrate its full thickness of 0 to 2200 m. Hydrocarbon exploration wells provide valuable insights; for example, large amounts of water at 45 to 60°C have been produced from some wells in the Welton oilfield from the limestone interval (Hirst, 2017).

Northern West Midlands

Early Carboniferous limestone extends westward to North Wales from the Peak District and is believed to underlie the Permo-Triassic Cheshire Basin (Figure 2 and Figure 3). Here, maximum temperatures may be as high as 150°C at 5 km depth, but evidence from boreholes is limited. The unit extends under the Manchester to Liverpool area. Into north Lancashire, the limestone is replaced by the more clay-rich rock types of the Craven and Bowland basins.

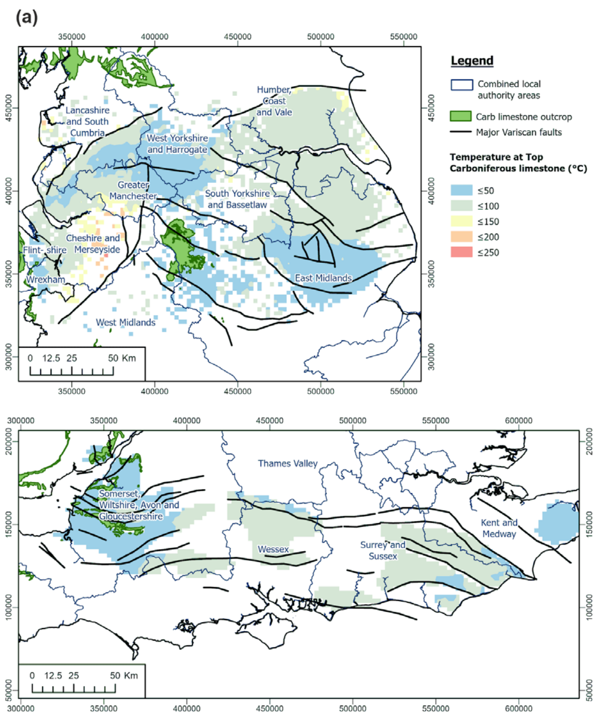

Figure 3 Map showing the temperature distribution at the top of the early Carboniferous limestone. Reproduced from Jones et al. (2023) Published by Elsevier Ltd. British Geological Survey © UKRI 2023.

Northern England

North of the early Carboniferous limestone shelf area of the Market Weighton High beneath Yorkshire, the time-equivalent rocks were mudstone-dominated in the Cleveland Basin and mixed mudstone/sandstone/limestone-dominated in Northumberland–Solway Basin.

Scotland

A complex series of mixed types of sedimentary and volcanic rocks were deposited in early Carboniferous times; there is not a thick limestone sequence.

Northern Ireland

There are Carboniferous limestone groups in the south-west of Northern Ireland that are classed as fracture and karst aquifers, with high aquifer productivity (Wilson et al., 2023). There may be geothermal potential where the limestone is buried beneath younger rocks, but no detailed studies have been published.

Southern province

Mendip Hills, Bath and Bristol

The best-known thermal waters from Carboniferous limestone aquifers in the UK are in the Bath and Bristol area, where temperatures up to 46.5°C are attained (Burgess et al., 1980). In Bath, meteoric waters derived from the Mendip Hills discharge through a cover of Triassic and Jurassic strata (Figure 4). Variscan faults and thrust planes are inferred to provide the required hydraulic connectivity. At Bristol, thermal water discharges directly from the Carboniferous limestone.

South Wales

The early Carboniferous limestone of South Wales displays a wide range of features that enhance groundwater flow through otherwise impermeable strata. Recent karstification, palaeokarst, dolomitisation and fracture flow are all well developed. A thermal spring at Taff's Well emanating from the Coal Measures is likely to originate in the underlying limestone at depths exceeding 3000 m in parts of the South Wales Coalfield. Geothermal energy taken from the thermal spring is currently used for space heating of the local primary school.

Wessex to Kent

The presence of the early Carboniferous limestone and hot water are proven by deep hydrocarbon exploration boreholes as far east as Kent. Temperatures are estimated to be 20 to 90°C in Kent and 40 to 100°C in Wessex (Jones et al., 2023).

Geothermal potential

The geothermal potential of the early Carboniferous limestone has been estimated. Narayan et al. (2021) uses a slab model of the reservoir deeper than 1 km to estimate a P50 heat-in-place value of 35 million GWh (129 EJ) for six regions in England and Wales. Jones et al. (2023) assesses a similar area using seismic and well data to statistically model depth, thickness, temperature maps and heat-in-place maps (Figure 5). This resulted in a heat-in-place range P10 to P90 of 1415 to 1528 EJ and a tentative potential heat recoverable of 106 to 222 GW. Both studies stressed further work is needed; for example,

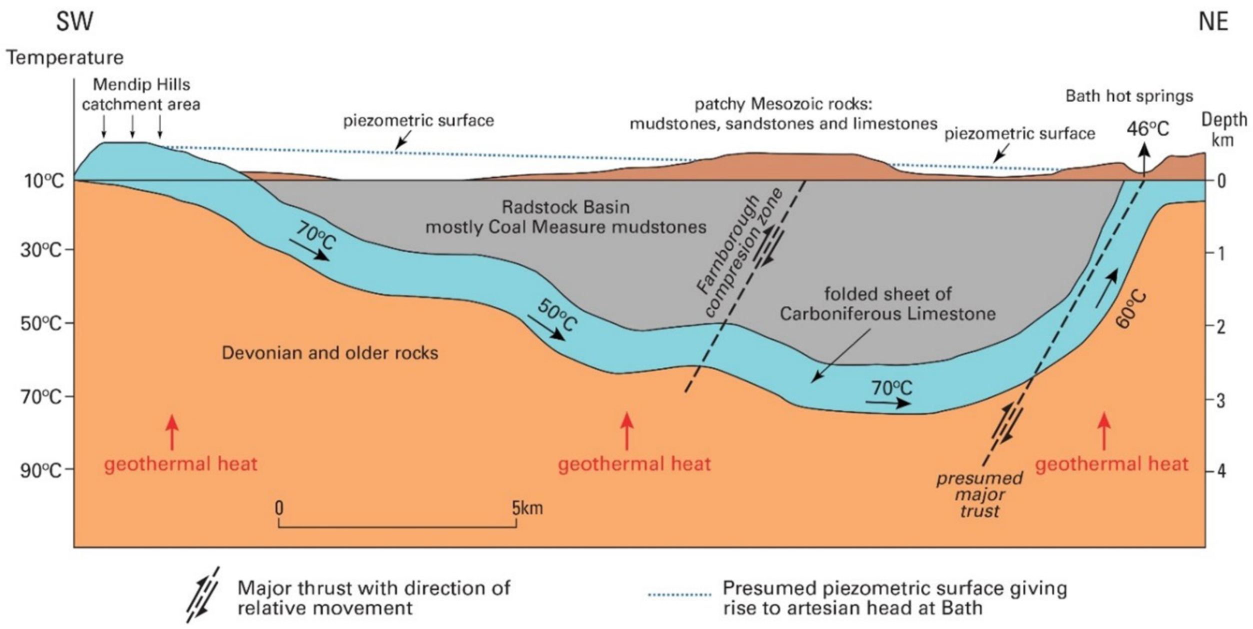

Figure 4 Model of groundwater flow from the Mendips to the Bath hot springs (after Pharoah et al. (2021)). © Pharaoh, T, Jones, D, Kearsey, T, Newell, A, Abesser, C, Randles, T, Patton, A, and Kendall, R. 2021. Licensed under a Creative Commons License (CC BY 4.0 NC).

to predict or identify deeply buried areas with sufficient flow rates (such as enhanced permeability zones) around faults, fractures and karst.

The studies showed that the early Carboniferous limestone is present at depth beneath many large urban centres in the UK and so has the potential to supply significant geothermal energy to heat networks.

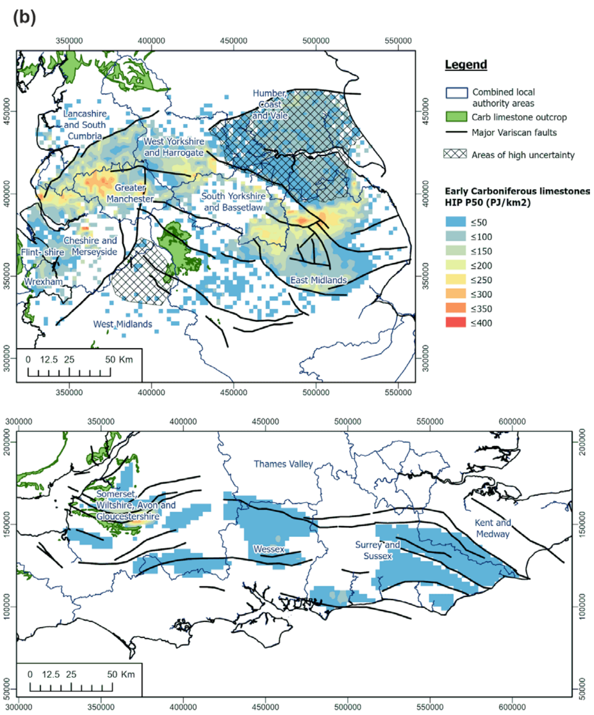

Figure 5 Map showing the distribution of heat-in-place (PJ/km^2) for the early Carboniferous limestone, based on the P_{50} result. Areas of high uncertainty are indicated.

Geothermal projects using the early Carboniferous limestone

In Belgium and the Netherlands, ongoing programmes of research and development are demonstrating that the early Carboniferous limestone is a proved resource for medium temperature geothermal doublet schemes.

At the Balmatt site at Mol, Belgium, the geothermal well doublet (Figure 6) targets a fractured carbonate reservoir at around 3.6 km depth, with temperatures up to 128°C (Bos and Laenen, 2017; Broothaers et al., 2020). It has supplied a heat network and is currently being used for investigative purposes. A pilot exploration well at Saint-Ghislain, Mons, at a depth of 2500 m and a temperature of 73°C, is used to heat houses, city infrastructure and greenhouses (Verbeke, 2016).

Figure 6 Geothermal well tapping early Carboniferous limestone at the Mol test site, Flanders, Belgium. BGS © UKRI/Tim Pharaoh.

In the Netherlands, a geothermal well at Venlo revealed Tournaisian- to Viséan-aged carbonates with better-than-expected reservoir properties, which are thought to be attributable to hydrothermal karstification (Reijmer, et al., 2017).

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Factsheet compiled by Ashley Patton following a previous version by Tim Pharaoh.