British Geological Survey

The geothermal resource of Permo-Triassic basins in the UK

Summary

- Permo-Triassic basins offer significant potential for geothermal energy in the UK
- Six Permo-Triassic basins in the UK are summarised here from legacy reports; the East Yorkshire and Lincolnshire Basin, the Wessex Basin, the Worcester Basin, the Cheshire and West Lancashire basins, the Carlisle Basin and the basins of Northern Ireland
- The total geothermal potential of the Permo-Triassic basins is estimated as 326 EJ[1], with 6 per cent of resource temperatures at over 60°C (mainly in the Wessex, Cheshire and Northern Irish basins), 41 per cent at 40 to 60°C, and 53 per cent at 20 to 40°C
- Many of these resources are close to urban settlements
- Permo-Triassic rocks can typically be exploited via geothermal doublets, for direct use heat, or with heat pumps for heating, cooling and thermal storage
- Geothermal energy can be used in district heating networks

Background

Consideration of geothermal energy use in the UK began in the 1970s. Funded by the European Union and the UK Government, a major review of resource potential was conducted by BGS in 1986 (Downing and Gray, 1986).

While high-temperature groundwaters associated with tectonic and volcanic origins are not found within the UK subsurface, low and medium enthalpy geothermal resources are present within sedimentary basins, which may be developed through mid-deep geothermal systems, ground-source heat pumps (GSHPs) or aquifer thermal energy storage (ATES).

One of the most promising of these resources is found within the sediments deposited in basins during the Permian and Triassic periods, 298.9 to 201.3 million years ago.

The resource

Permo-Triassic sedimentary rocks are found extensively across the UK, both at outcrop and deep beneath the surface (Figure 1). These basins contain vast amounts of heat because temperature increases with depth. Groundwater circulating at depth within these basins can be exploited for geothermal energy where subsurface conditions are favourable and where they coincide with areas of high heat demand.

1 EJ = 1 × 1018 J

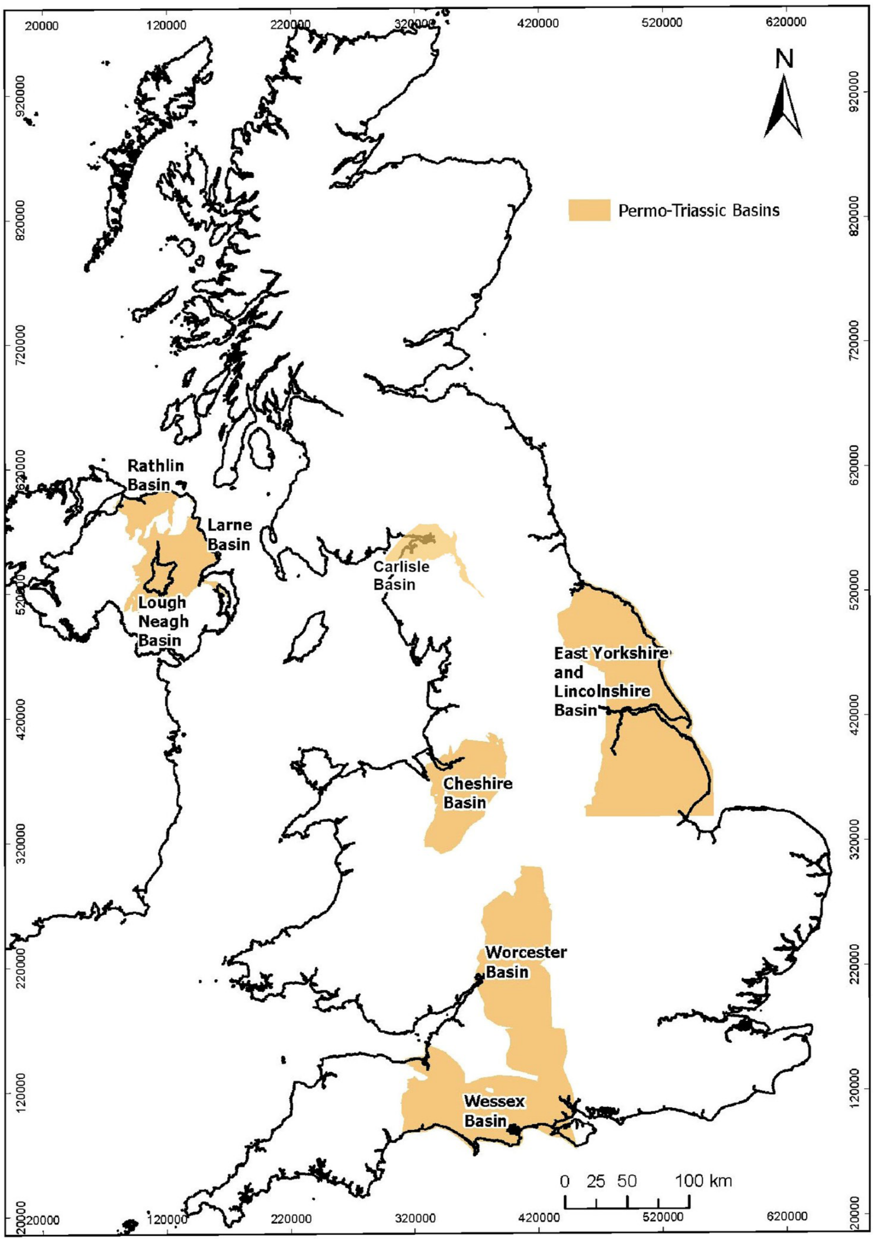

Figure 1 Map showing the distribution of Permo-Triassic basins in the UK, where considered for mid-deep geothermal potential. BGS © UKRI.

In the UK's Permo-Triassic basins, sandstones are found at great enough depths for their groundwater to be of sufficiently high temperature for geothermal development. These sandstones often have permeabilities in the range of five to several thousand milliDarcies (mD) and can yield the high flow rates required to make the geothermal resource economically viable.

The total heat-in-place geothermal potential of the Permo-Triassic basins is estimated at 326 EJ (Abesser et al., 2023), of which 6 per cent is derived from groundwater temperatures above 60°C, 41 per cent at 40 to 60°C and 53 per cent at 20 to 40°C (Downing and Gray, 1986). At temperatures above 60°C, the geothermal source may be exploited directly for heating applications but, for lower temperatures, the use of heat pumps may be needed.

Regional geothermal prospects

There are six Permo-Triassic basins in the UK of suitable depth and thickness to warrant interest from a mid-deep geothermal perspective.

These are:

- the East Yorkshire and Lincolnshire Basin
- the Wessex Basin
- the Worcester Basin
- the Cheshire and West Lancashire basins

- the Carlisle Basin
- the basins of Northern Ireland

In other areas, such as around Nottingham, the same rocks buried less deeply have shallow geothermal (ground-source heating; cooling; storage) potential.

A summary of the mid-deep 'identified resource' estimated for each basin is provided in Table 1.

East Yorkshire and Lincolnshire Basin

The East Yorkshire and Lincolnshire Basin is the onshore extension of the Southern North Sea Basin. Its base is 2 km deep; groundwater circulating at these depths can easily reach temperatures exceeding 60°C and most of the basin is of interest for geothermal exploration.

Principal aquifers within the basin include Permo-Triassic sandstones and limestones, including the Yellow Sands Formation, the Permian Basal Breccia and the Sherwood Sandstone Group (Shand et al., 2002), all of which have geothermal potential.

The lower Permian sandstones of East Lincolnshire are between 30 and 60 m thick. The Sherwood Sandstone Group has a maximum thickness of 500 m, south of Bridlington. In east Lincolnshire, it ranges from 100 m thick at The Wash to 400 m thick at the Humber. The rocks dip towards to the east, reaching depths of 1700 m in Holderness and north-east Lincolnshire.

The mean permeability of the lower Permian sandstones is 150 mD (1.48×10^{-13} m^2/d), giving a transmissivity from 5 to 10 Darcy metres (Dm). Porosity is around 20 to 25 per cent in Lincolnshire and 25 to 30 per cent in Yorkshire. From the Tees to The Wash, at the coast, estimated temperatures are 50°C, while around Flamborough Head and Holderness, 70°C is predicted. In Lincolnshire, the temperature is estimated to exceed 60°C.

The Sherwood Sandstone Group predominantly comprises medium- to coarse-grained, clean, well-graded sandstones. Porosity exceeds 30 per cent but is lower in finer lithologies, reaching 25 per cent in selected boreholes between Nottingham and Bridlington. In north Yorkshire and Durham, porosity is 10 to 20 per cent. The mean permeability is 250 mD (2.47×10^{-13} m^2/d).

The top of the aquifer is found at depths of 800 to 1200 m and predicted temperatures exceed 50°C to the north and south of the Humber, and 40°C extensively across the rest of the basin (Figure 2). The average geothermal gradient is 31.9°C/km from borehole and well data points (Busby, 2014). The total heat-in-place geothermal resource for areas of 20 to 40°C, 40 to 60°C and over 60°C are 245.3 EJ, 190.2 EJ and 30.6 EJ, respectively (Downing and Gray, 1986).

It is worth noting that the Permian Zechstein Group contains evaporites, so care will be needed not to remobilise these during geothermal drilling and exploration.

Wessex Basin

The Wessex Basin is a sedimentary basin comprising Permian to Tertiary rocks. The basin flanks the southern side of the London Platform and extends under the Weald and westwards to Devon. Although the basin contains several aquifers, permeabilities have been judged too low to be economically viable in those areas where temperatures are suitable for geothermal potential, apart from in the Sherwood Sandstone Group (Downing and Gray, 1986).

The Sherwood Sandstone Group comprises a series of breccias and conglomerates, overlain by cyclically deposited, medium-grained sandstones (Bearcock and Smedley, 2012). Permeability is reported as irregular in this unit, depending on cementation.

In Dorset, the Sherwood Sandstone Group is 160 to 280 m thick, providing the best geothermal potential in the Wessex Basin. The thickest successions can be found in the Winterbourne Kingston Trough, but these do not have the most favourable porosity or permeability.

Thickness and transmissivity of the Sherwood Sandstone Group in the Wessex Basin increase westward from Southampton. Temperatures exceed 60°C over an appreciable area (Figure 3) and transmissivity is over 10 Dm. Temperatures exceed 40°C to the west of Bridport and Yeovil, and 70°C north-west of Bournemouth. The average geothermal gradient for the basin is 34.5°C/km (Busby, 2014). Mean porosity is 25 per cent while permeability is 5 mD (4.93×10^{-15} m^2/d). The total heat-in-place geothermal resource for the basin is 26 EJ (Downing and Gray, 1986).

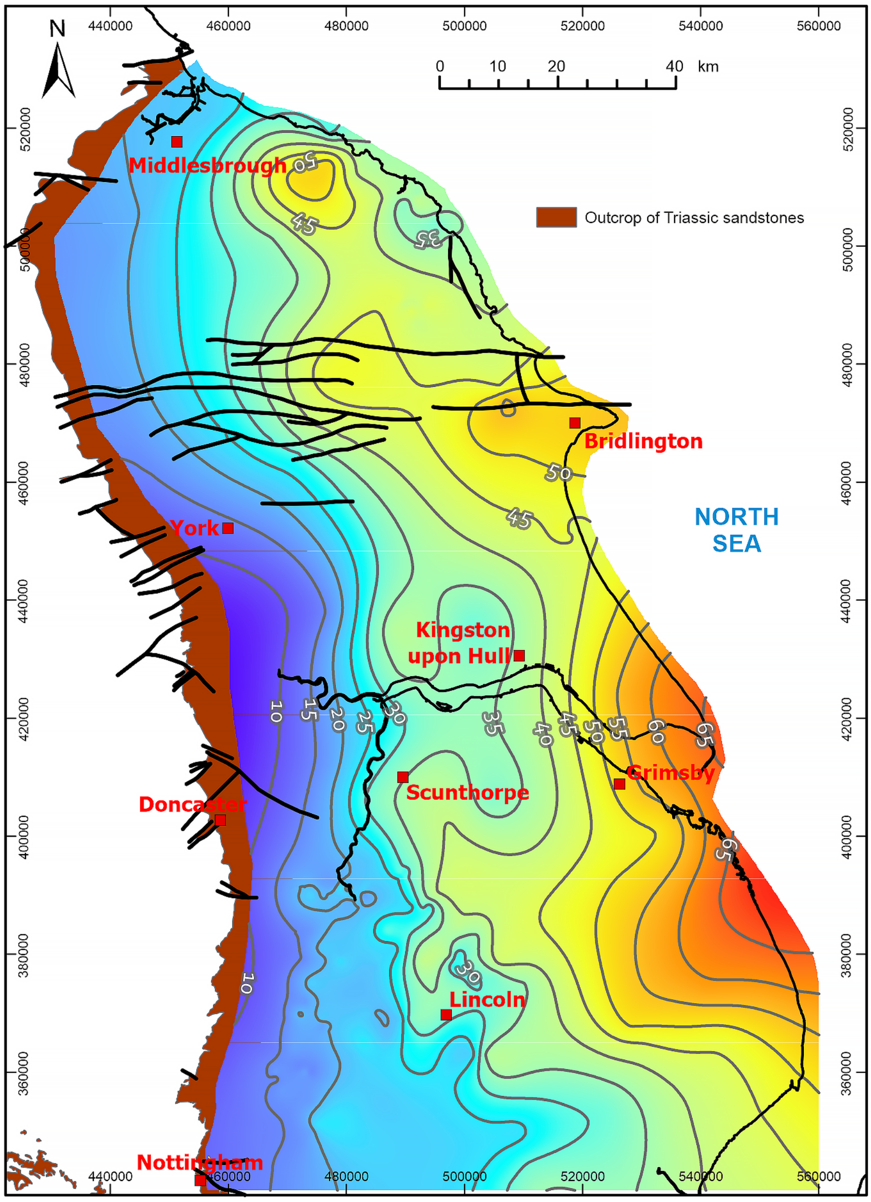

Figure 2 Estimated temperature at the mid-depth of the Sherwood Sandstone Group in the East Yorkshire and Lincolnshire Basin. Contours shown at 5°C intervals. (From Rollin et al., 1995.)

Worcester Basin

The Worcester Basin extends from Droitwich in the north to Cirencester in the south, and is located east of the Malvern Hills. In this basin, Permo-Triassic sandstone is overlain by the Mercia Mudstone Group and has restricted outcrop along the western and northern boundaries. Further from the margins, boreholes have proved great thicknesses of sandstone belonging to four major arenaceous formations:

- Bridgnorth Sandstone Formation (Permian): lightly cemented grains, but this does not significantly reduce porosity nor permeability; maximum thickness is 938 m at Kempsey
- Chester Formation (Lower Triassic): coarse, cross-bedded sandstone, locally heavily cemented; maximum thickness of 175 m
- Wildmoor Sandstone Member (Lower Triassic): similar characteristics to the Bridgnorth Sandstone Formation; maximum thickness of 430 m, although thinly developed on structural highs
- Helsby Sandstone Formation (Middle Triassic): fining-upward, cyclic deposits of conglomerates, sandstones, siltstones and mudstones; average thickness of 500 m, which is uniform across much of the basin (Downing and Gray, 1986; Smedley et al., 2005)

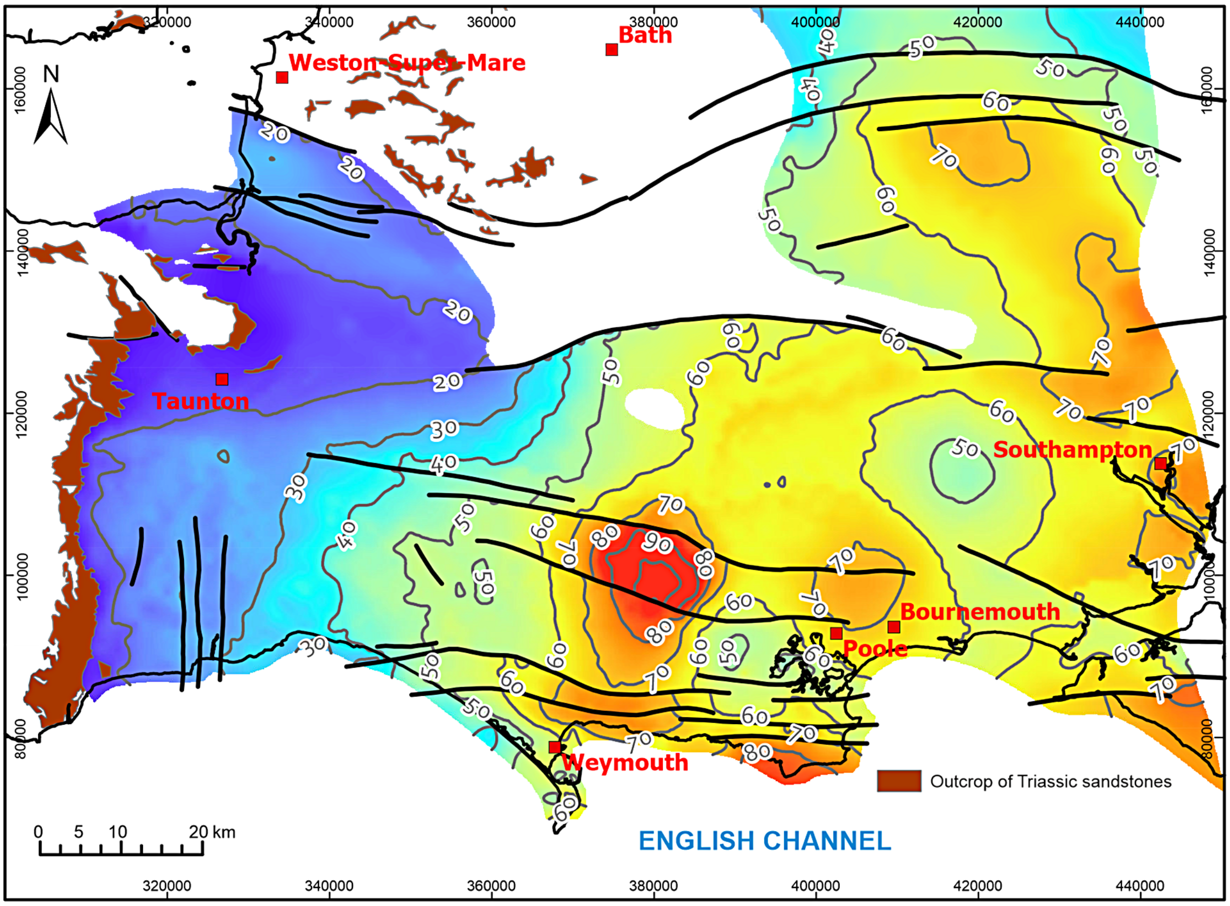

Figure 3 Estimated temperature at base of Sherwood Sandstone Group in the Wessex Basin. Contours shown at 10°C intervals. (From Rollin et al., 1995.)

The Bridgnorth Sandstone Formation, Wildmoor Sandstone Member and Bromsgrove Sandstone Formation are all part of the Sherwood Sandstone Group and form aquifers of geothermal potential. Collectively, they have a maximum thickness of over 2000 m, with a thickness greater than 1000 m over much of the basin. Average permeability is 100 mD (9.87×10^{-14} m^2/d) and transmissivity averages 80 Dm for the Triassic formations and 100 Dm for the Bridgnorth Sandstone Formation.

Temperatures have been measured between 20 and 40°C with an average geothermal gradient of 18°C/km. In the deepest part of the basin, north-west and south-east of Evesham, temperatures are predicted to reach 50°C (Figure 4). The geothermal resource is estimated at 84.7 EJ.

The greatest potential is interpreted in the north of the basin, where boreholes of 2000 to 2500 m depth would be required. In the south, boreholes of 1700 m are predicted to encounter the geothermal target aquifers (Downing and Gray, 1986).

Cheshire and West Lancashire basins

The Cheshire and West Lancashire basins are situated between the Pennine uplands of northern England to the east and the Irish Sea and Welsh borderlands to the west. The Permo-Triassic deposits infill the pre-Permian topography, resulting in significant lateral thickness variations.

The sequence comprises:

- aeolian sandstones of the Collyhurst Sandstone and Kinnerton Sandstone formations
- Manchester Marls Formation (which may act as an aquiclude)
- Chester Formation (a series of sandstones and conglomerates)
- Wilmslow Sandstone Formation
- Helsby Sandstone Formation

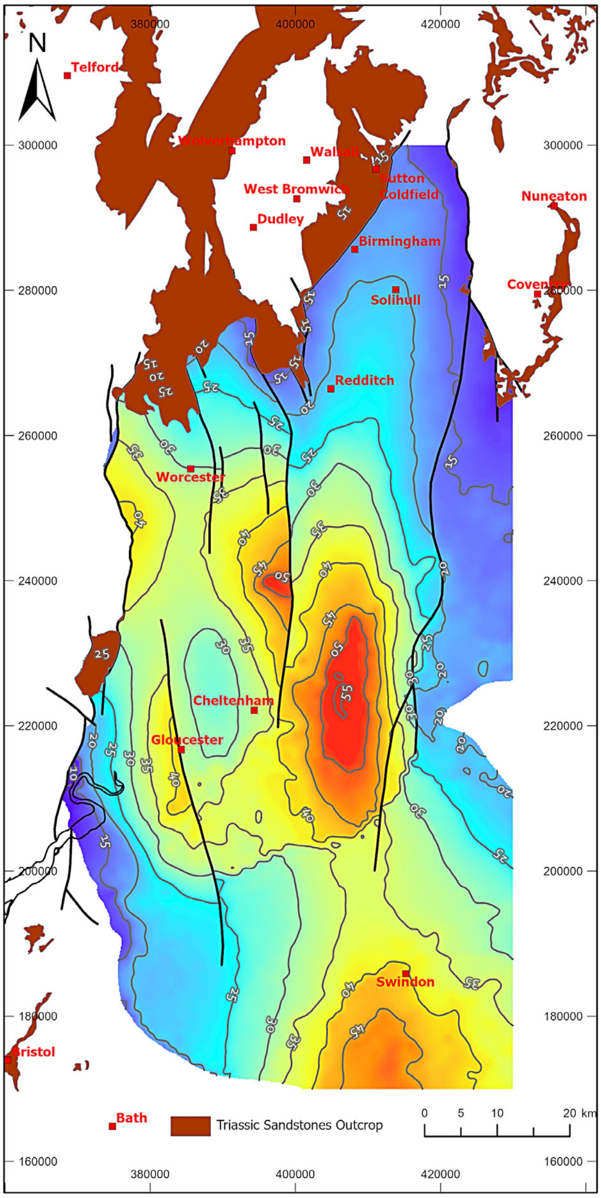

Figure 4 Estimated temperature at base of Permo-Triassic in the Worcester Basin. Contours shown at 5°C intervals (From Rollin et al., 1995).

All are overlain by the confining Mercia Mudstone Group (Griffiths et al., 2002; Jackson, 2012).

At the base of the Permo-Triassic rocks, the Cheshire Basin reaches a depth of more than 4 km to the north-east of Crewe and 3 km in Crewe itself, over an area of 350 km^2. In the West Lancashire Basin, the maximum depth is 2 km below the Ormskirk–Southport Plain and 3 km below the Fylde (Downing and Gray, 1986).

The geothermal gradients measured in boreholes for both basins are low (9 to 27°C/km (Busby, 2014)) due to low heat flow and the high thermal conductivity of the Permo-Triassic sandstones. However, owing to their depth, temperatures in the Cheshire basin can reach over 70°C. Porosities average at 15 to 20 per cent, with permeability ranging from 10 to100 mD (9.87×10^{-15} to 9.87×10^{-14} m^2/d).

The temperature in the sandstones exceeds 40°C over large parts (550 km^2) of the area and in some parts (more than 320 km^2) it is over 60°C. In both these areas, transmissivity is thought to exceed 10 Dm. In the West Lancashire Basin, the Permo-Triassic sandstones are 1800 m deep with temperatures in the range of 20 to 40°C. The total heat-in-place geothermal resource for the two basins is 67 EJ (Downing and Gray, 1986).

Carlisle Basin

The principal aquifers are the Helsby Sandstone and Penrith Sandstone formations and the St Bees Sandstone Member, with the Penrith Sandstone Formation of most interest for geothermal exploration.

The sandstones are situated at relatively shallow depths compared with other areas (1700 m at their deepest). Temperatures are predicted to be above 40°C in only a small area to the east of Silloth; elsewhere, they range from 20 to 40°C. The mean estimated temperature is 33°C. Porosity values are up to 26 per cent (mean values for Helsby Sandstone and Penrith Sandstone formations and St Bees Sandstone Member are 20 per cent, 15 per cent and 14 per cent, respectively).

The Penrith Sandstone Formation is a productive aquifer but has varying degrees of cementation depending on the area, as well as highly variable grain sizes. Its permeability ranges from 100 to several thousand mD. The St Bees Sandstone Member has a typical intergranular permeability of 200 to 600 mD (1.97×0^{-14} to 5.92×10^{-14} m^2/d), with values up to 2000 mD (1.97×10^{-12} m^2/d). Properties are less favourable towards the north side of the Solway Firth (10to 80 mD (9.87×10^{-15} to 7.90×10^{-14} m^2/d) permeability; 17 to 23 per cent porosity).

The deep geothermal resource for the Carlisle Basin is estimated at 1.4 EJ, which is small compared with the other Permo-Triassic basins of the UK (Downing and Gray, 1986). However, there is potential for local usage for GSHPs, storage and agricultural purposes. Additionally, the hottest parts of the aquifer underlie rural areas with no significant urban centres.

Northern Ireland

The basal sediments of Northern Ireland's Permo-Triassic sedimentary basins (Rathlin; Lough Foyle; Lough Neagh; Larne) comprise coarse-grained, variably cemented lower Permian sandstones and breccias, overlain by upper Permian mudstones, sandstones, carbonates and local evaporites. These in turn are overlain by the Triassic Sherwood Sandstone Group. This unit comprises fine- to medium-grained sandstones with some interbedded siltstones and mudstones. In total, Permo-Triassic sandstones exceed 1000 m cumulative thickness in some parts of the basins (Figure 5).

The Sherwood Sandstone Group constitutes the main geothermal target; however, its reservoir quality is less well documented than the rest of the UK, especially at depths below 1500 m. The most productive horizons are encountered in the upper 200 to 250 m of the unit. Here, transmissivity likely exceeds 10 Dm, with a permeability of 50 to 100 mD (4.93×10^{-14} to 9.87×10^{-14} m^2/d) based on the Larne No. 2 borehole. Reservoir quality data from other boreholes indicate that average permeability may be up to 220 mD, with some samples having permeability in excess of 3000 mD.

Porosity in the Sherwood Sandstone Group is on average 16 to 27 per cent. The average geothermal gradient in the basins is 28 to 35°C. Based on modelled burial depth, temperatures within the Sherwood Sandstone Group are predicted to exceed 40°C across much of the subcrop and, in an area of 300 km^2 around Lough Neagh, deep burial indicates that temperatures greater than 60°C are likely. The geothermal resource estimate in these basins is 60 EJ with a thermal yield of 1 to 4 MW; however, much of the area is rural with only small towns (Downing and Gray, 1986).

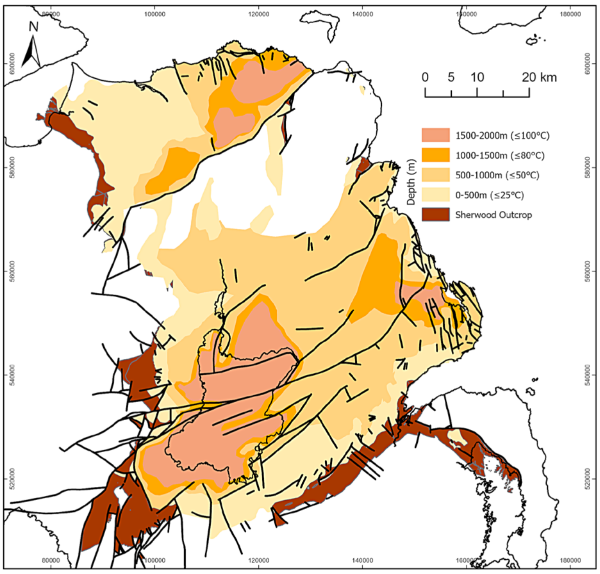

Figure 5 Depth map of top Sherwood Sandstone Group in Northern Ireland, showing indicative temperature estimates based on geothermal gradient. Assumed temperatures are given based on estimated regional geothermal gradient by Raine et al., 2020.

Table 1 Summary of the identified resources of the Permo-Triassic sandstones. As first reported in Downing and Gray (1986).

Basin	Aquifer	Identified resource (EJ)			
		Reject temperature: 10°C		Reject temperature: 30°C	
		0.1*	0.25*	0.1*	0.25*
E Yorks & Lincs	SS	21.9	54.8	4.2	10.6
	BPS	0.87	2.23	0.41	1.02
Wessex	SS	2.6	6.5	1.3	3.3
Worcester	P-T	8.5	21.2	0.6	1.4
Cheshire	SS	3.0	7.4	0.9	2.1
	P-T	3.5	8.7	1.5	3.8
W Lancs	P-T	0.2	0.5	-	-
Carlisle	P-T	0.13	0.32	-	-
N Ireland	SS	6.1	14.9	1.8	4.7
Totals		**46.8**	**116.5**	**10.7**	**26.9**

* Maximum recovery factor as defined by Lavigne, 1978
SS: Sherwood Sandstone Group
PBB: Permian Basal Breccia
P-T: Permo-Triassic sandstones (undifferentiated)

Demonstration of geothermal technologies

Resource assessments for the geothermal potential of the Permo-Triassic basins of the UK have been carried out (Downing and Gray, 1986; Jackson, 2012; Hurter and Haenel, 2002; Pasquali et al., 2010; Rollin et al., 1995). They concluded that the Permo-Triassic rocks offer significant geothermal resource potential in the UK. Smaller cities and towns are located in these areas, rather than the major population centres of the UK. There is also significant potential for shallow systems.

At the time of writing (November 2024) there is currently only one direct-heat use geothermal scheme in the UK; however, several GSHPs have been installed targeting the Permo-Triassic units. The scheme in Southampton is located on the east edge of the Sherwood Sandstone Group in the Wessex Basin and yields water heated to 76°C from depths of 1725 to 1749 m. It was operational between 1988 and 2020 but was offline at the time of writing due to a technical issue (Abesser and Walker, 2022). It has a capacity of 2.8 MW_{th}.

Permo-Triassic rocks are the target of a unique geothermal underground laboratory. The UK Geoenergy Observatory in Cheshire is a research facility comprising 21 boreholes drilled to around 100 m depth into the Sherwood Sandstone Group. The focus is on shallow geothermal and aquifer thermal energy storage, with numerous geophysical, temperature and hydrogeological sensors, multi-level groundwater monitoring and hydraulic control and infrastructure for heating and cooling of the subsurface.

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