British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

UK data for geothermal resource assessments

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UK data for geothermal resource assessments

Outline

1. Data availability
2. Sub-surface temperatures
3. The EGS resource
4. Deep saline aquifers

Publicly funded UK geothermal projects

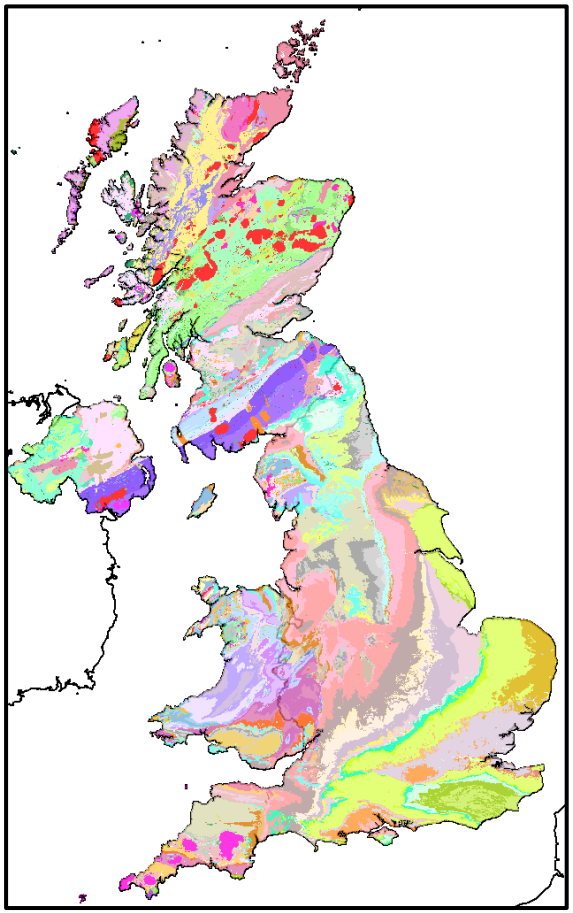
Geothermal Energy Programme (1977-1988) – funded by the UK Department of Energy and the European Commission (BGS/Imperial College/Open University)

Rosemanowes HDR project (1977-1991)) – funded by the UK Department of Energy and the European Commission (Camborne School of Mines)

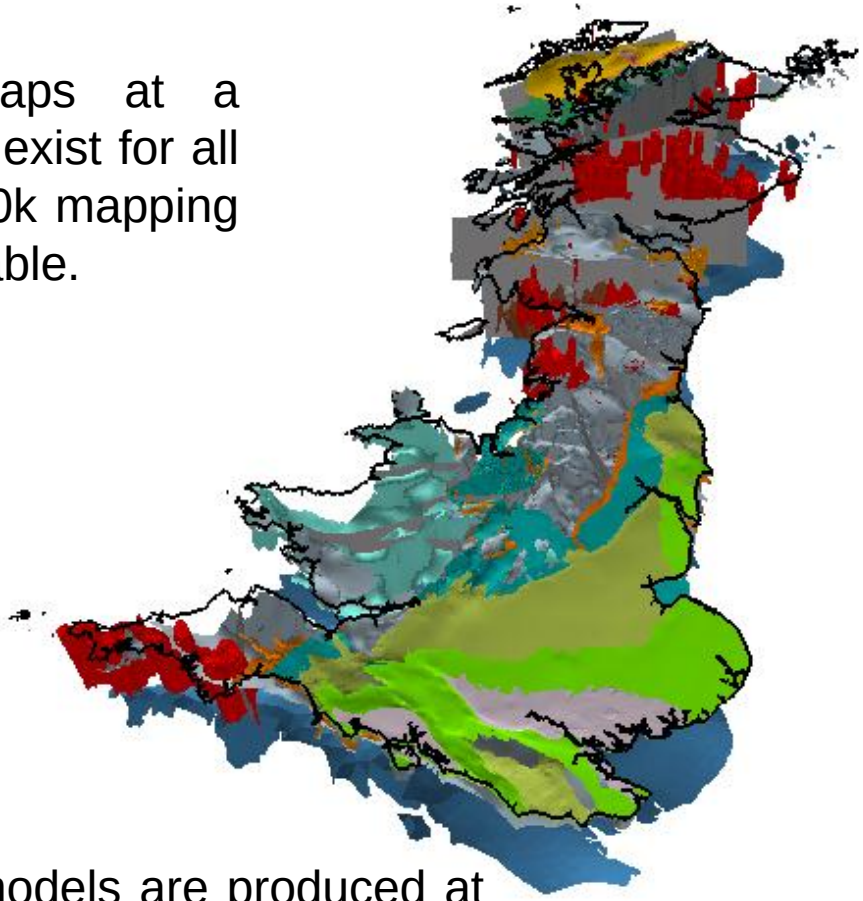
Atlas of geothermal resources in Europe: UK revision (1995) – EU Joule II project (BGS)

Data availability

Geological mapping started in England over 200 years ago and since then there has been extensive onshore exploration for minerals, coal, oil, gas and geothermal resources.

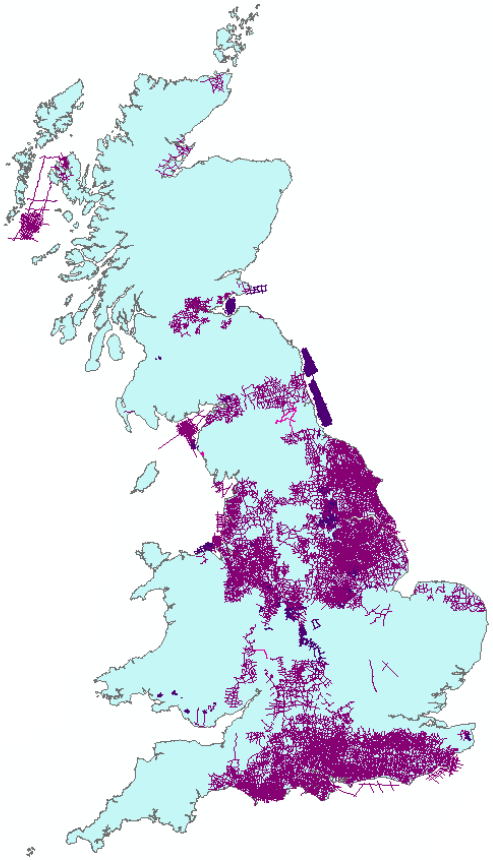


Geological maps at a scale of 1:50k exist for all areas and 1:10k mapping is widely available.



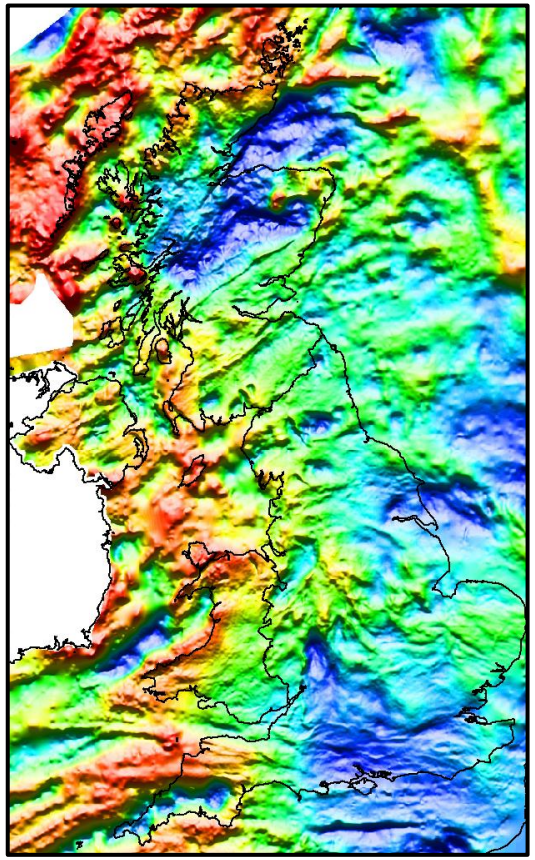
3D models are produced at a scale of 1:250k for regional areas

Data availability

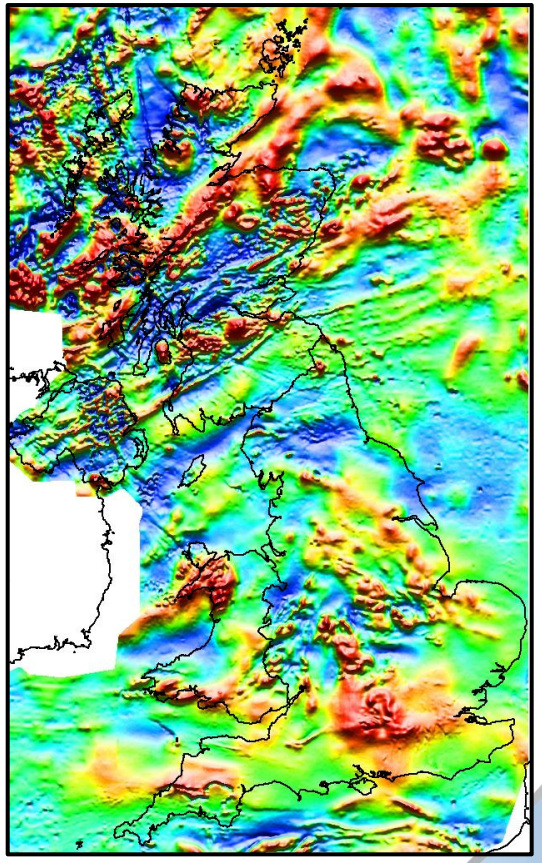


Seismic reflection lines

Regions underlain by sedimentary basins have good coverage



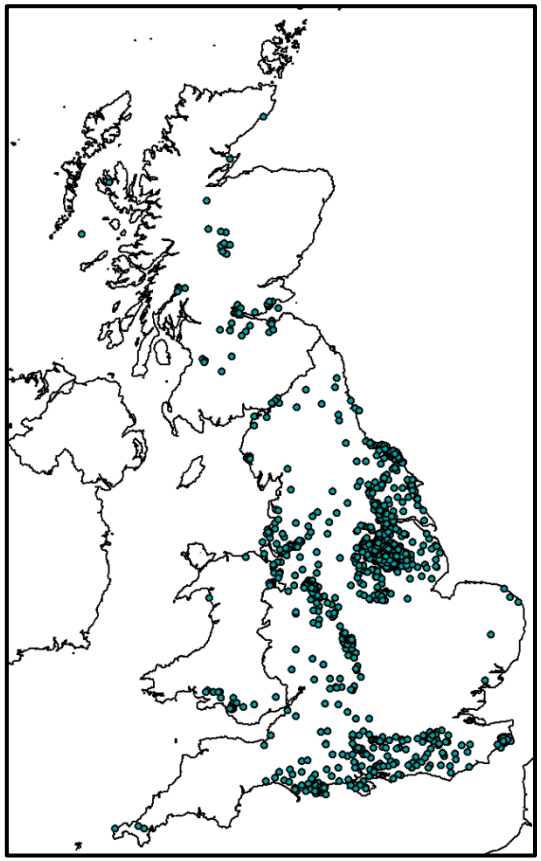
Gravity data (~ 1 station per sq km)



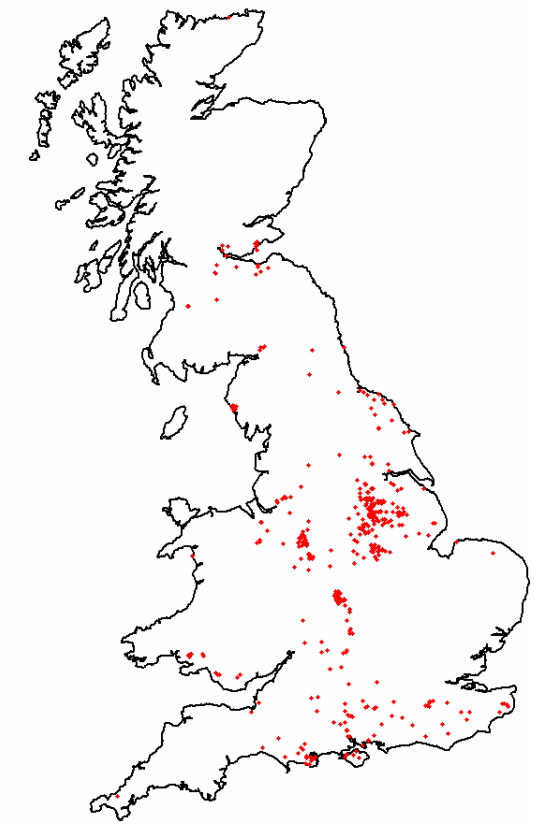
Magnetic data

Data availability

There are over a million onshore boreholes, although most are very shallow.

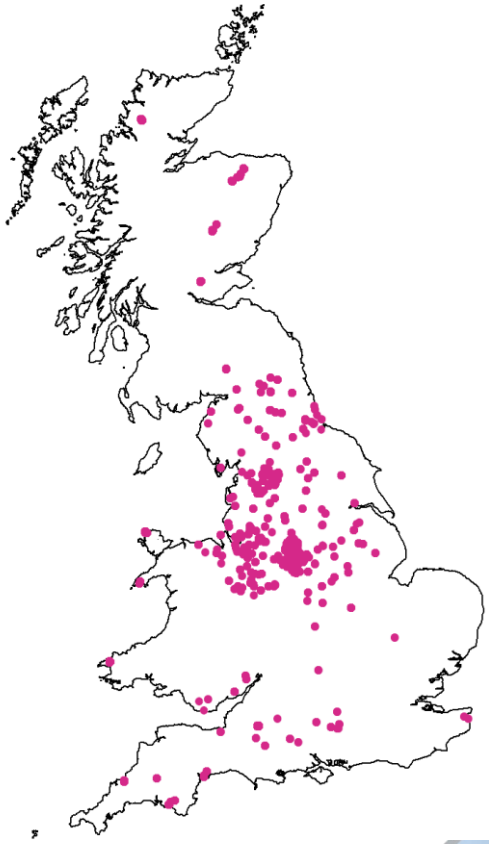


There are 1765 boreholes over 1 km deep

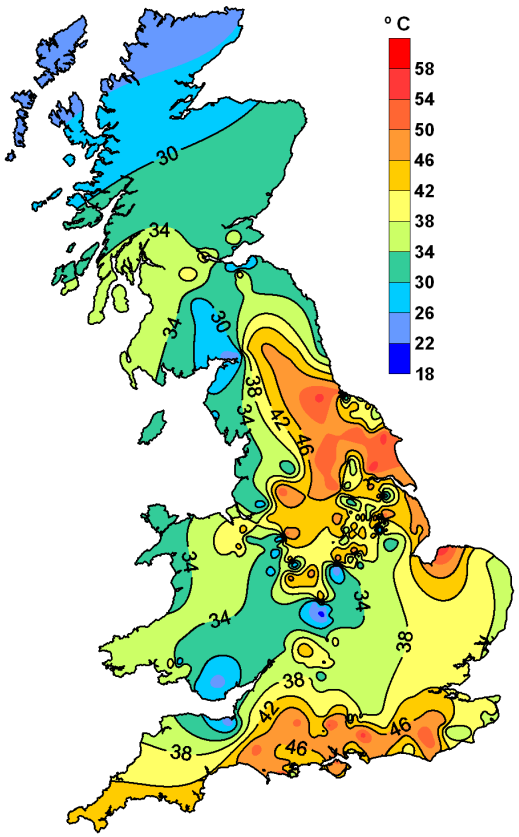


There are over 544 sites with a downhole temperature 1 km or deeper

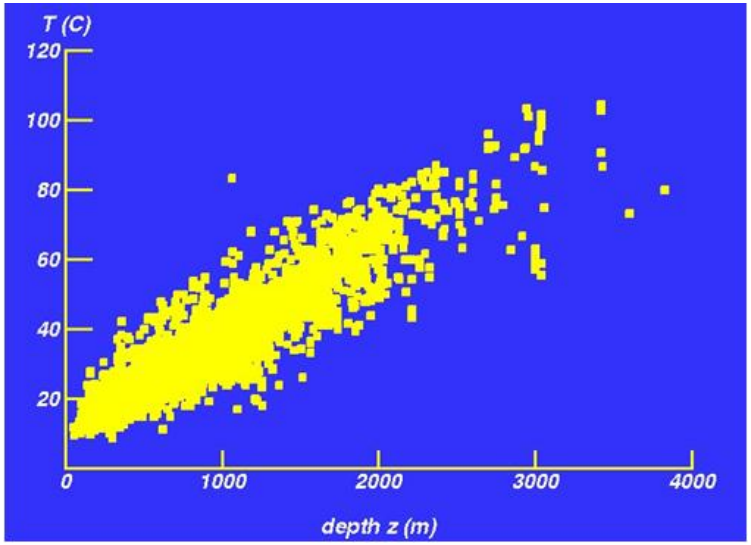
18,000 borehole geochemical samples



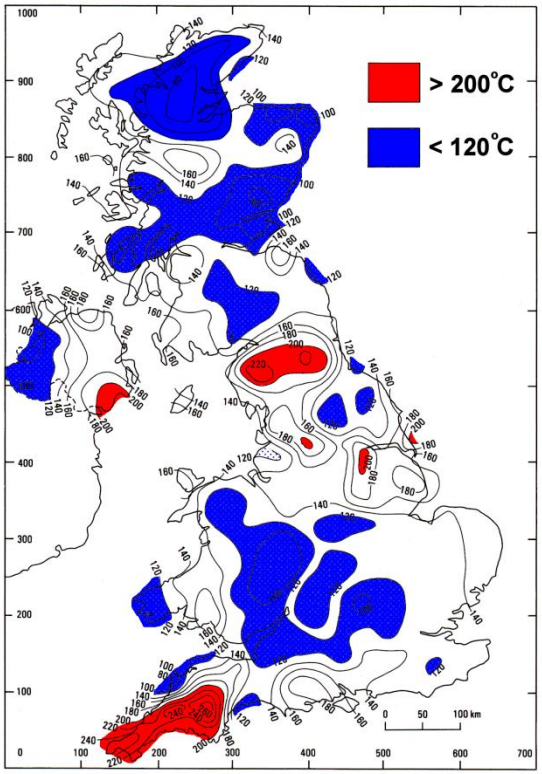
Temperatures



Measured temperatures at 1km below ground level, the median temperature is 38 °C.

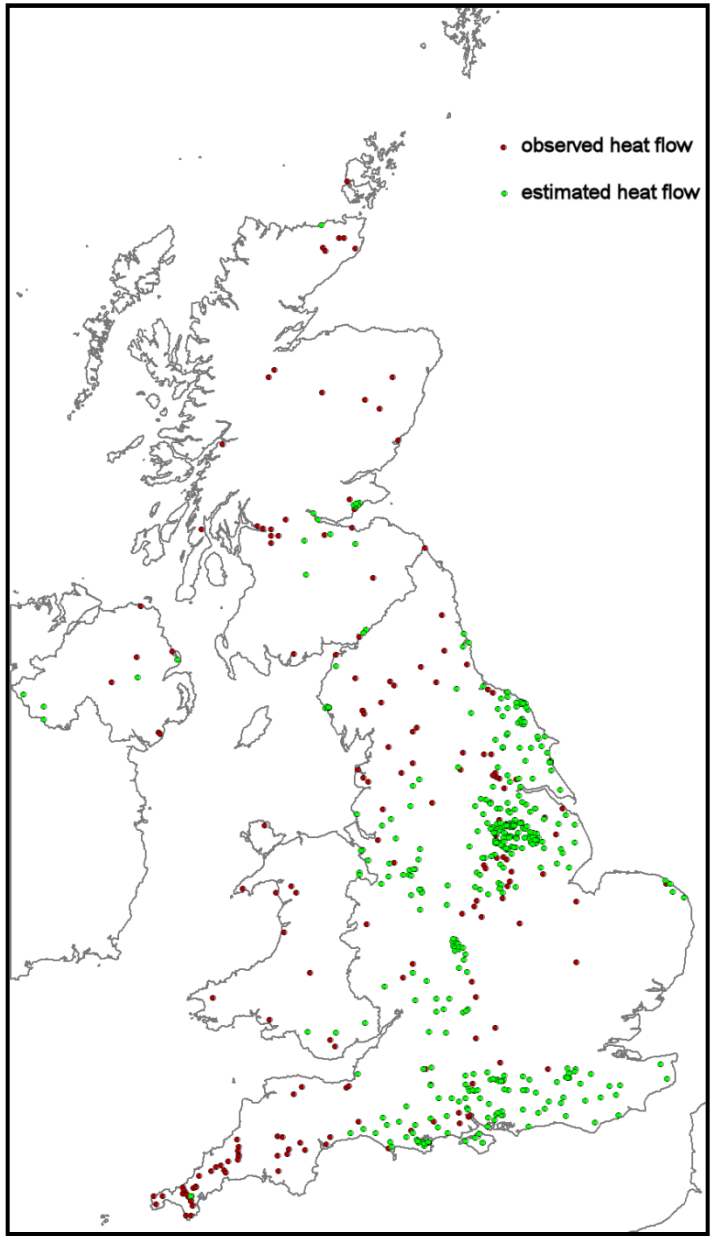


Measured temperature vs depth for over 2600 temperatures from over 1150 sites.



Estimated temperatures at a depth of 7 km.

The EGS resource

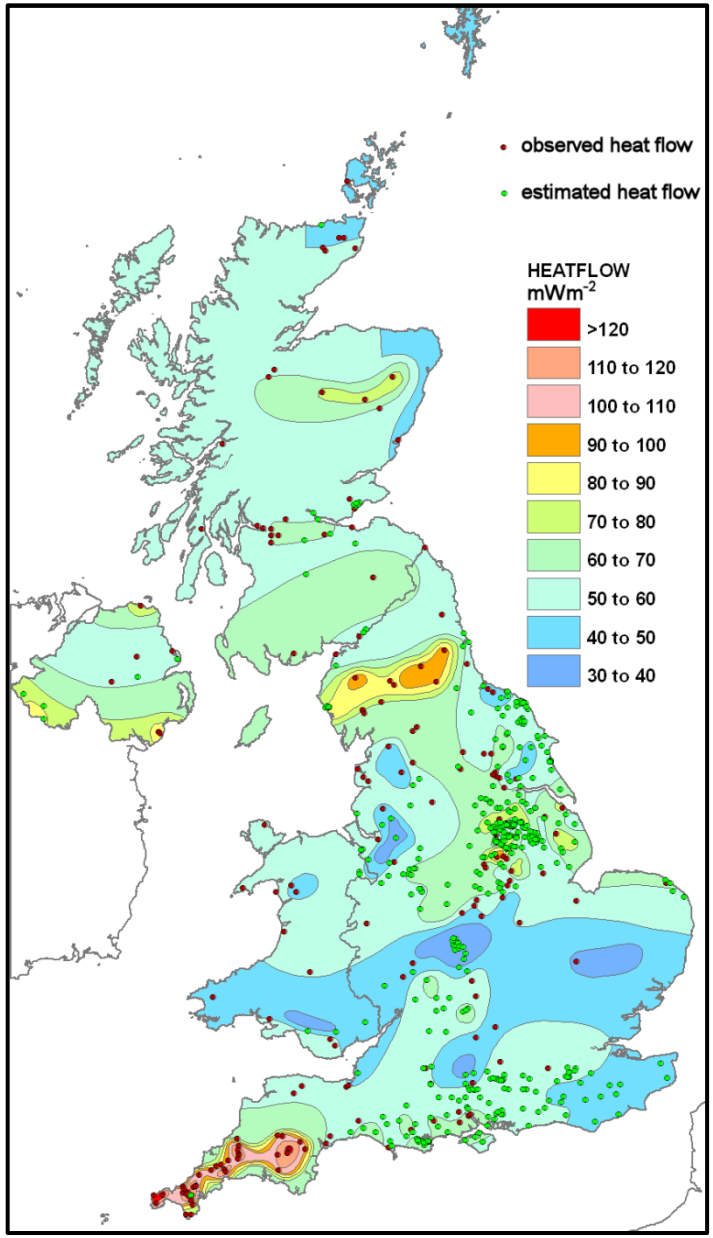


Temperatures at depth are determined by the heat flow and the thermal conductivities of the strata.

184 observed heat flow measurements based on equilibrium temperatures and laboratory thermal conductivities.

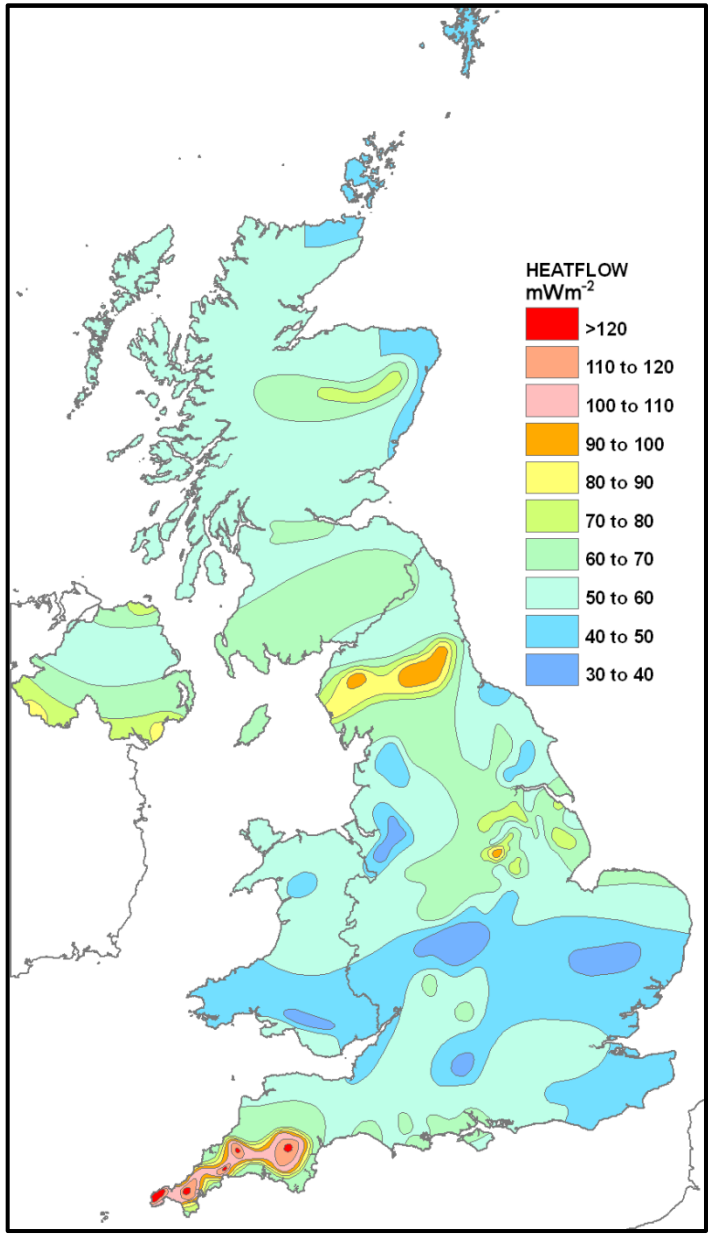
504 estimated heat flows based on corrected BHTs and estimated thermal conductivities.

The EGS resource



The distribution of the heat flow measurements is very uneven. Most boreholes were drilled for oil, gas or coal. Scotland, Wales and parts of eastern England are very poorly sampled.

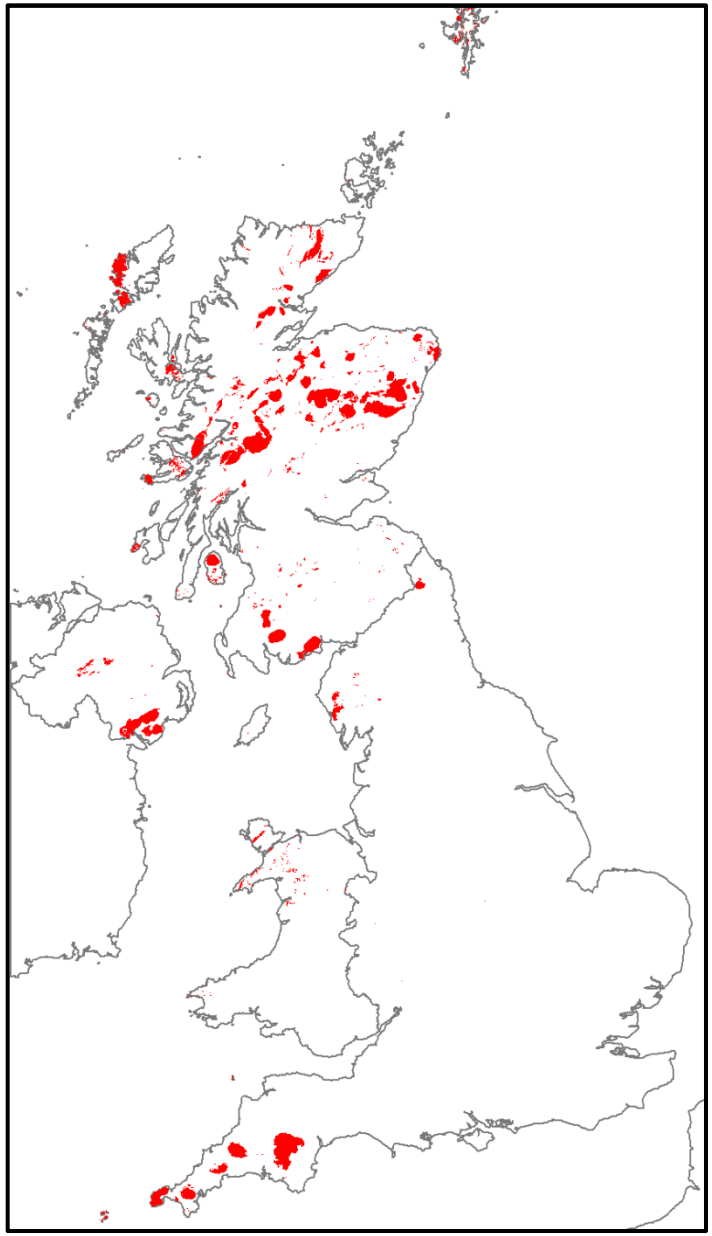
The EGS resource



Heat flow

- Heat flow values peak over the radiogenic granites with values up to 130 mW m^{-2}.
- Elsewhere, an average of 58 ± 16 mW m^{-2}.
- Average UK geothermal gradient is 26° C per km, but locally it can be in excess of 35° C per km.

The EGS resource

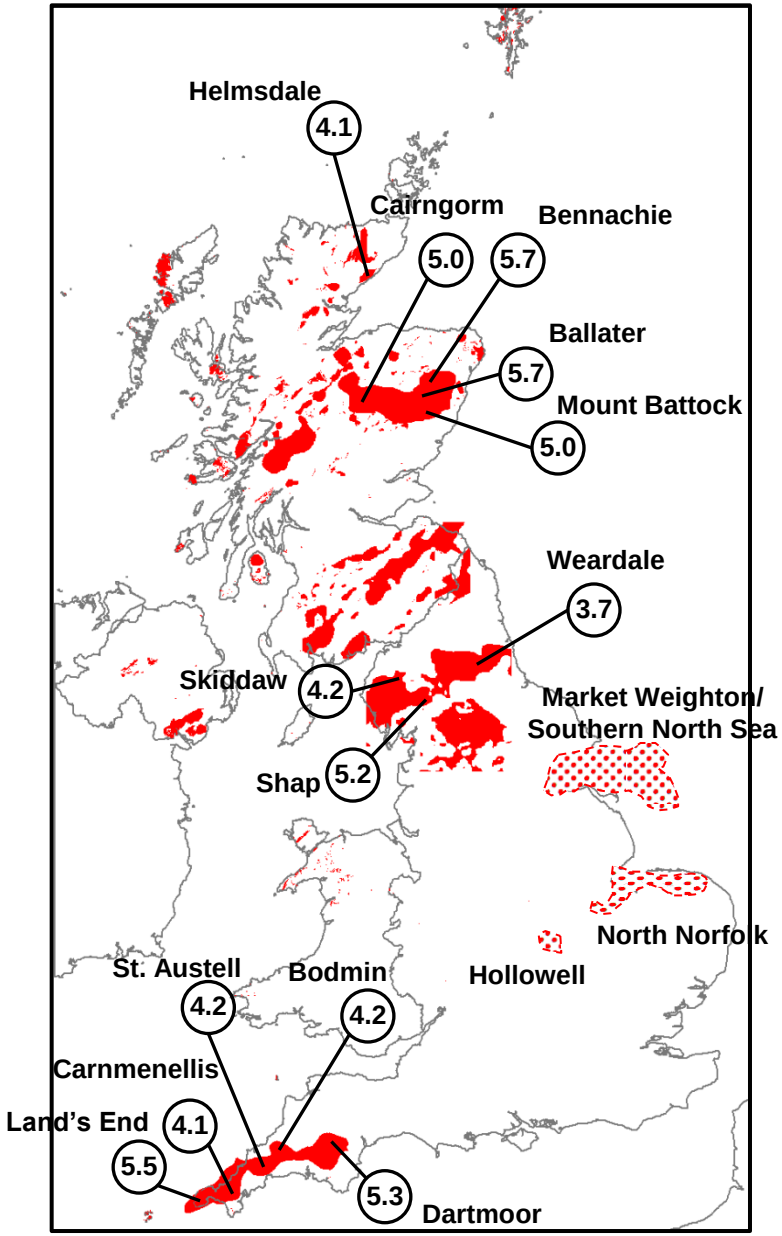


Enhanced temperatures at depth are most likely to be associated with the radiogenic granites.

Outcrops of granite occur in

- The southwest of England
- Northern England
- Scotland
- Northern Ireland

The EGS resource



5.0 Heat production (μWm^{-3}) only shown for values > 3.5 μWm^{-3}

Buried granite (unproven)

The subsurface distribution of granite has been derived from interpretations of gravity data.

Most outcropping granites have been geochemically sampled from surface and borehole samples

High heat producing granites occur in

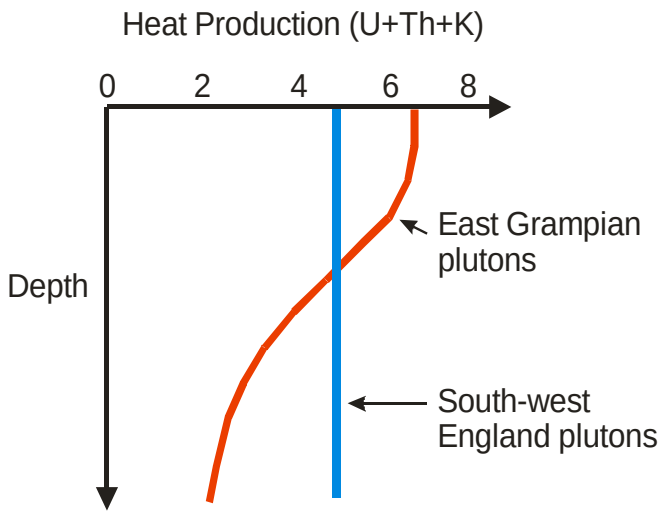
- The eastern Highlands batholith
- Lake district and northern England
- Cornubian batholith (SW England)

The Accessible Resource Base for EGS has been estimated as 3.58×10^{10} TJ

The EGS resource

East Grampians batholith found to have high heat production, but low heat flow.

Region	Heat production ($\mu W/m^{-3}$)	Heat flow (mW/m^{-2})
East Grampians	**6.5**	**68.9**
Northern England	**4.1**	**84.8**
South-west England	**4.7**	**119.6**



Palaeoclimate corrections have been applied to the East Grampian heat flow boreholes with an estimated surface temperature model dating back 160k years.

	Uncorrected (mWm^{-2})	Corrected (mWm^{-2})
Ballater	74	94
Benachie	86	109
Cairngorm	71	91
Mount Battock	65	86

Increase of 29% in heat flow due to correction.

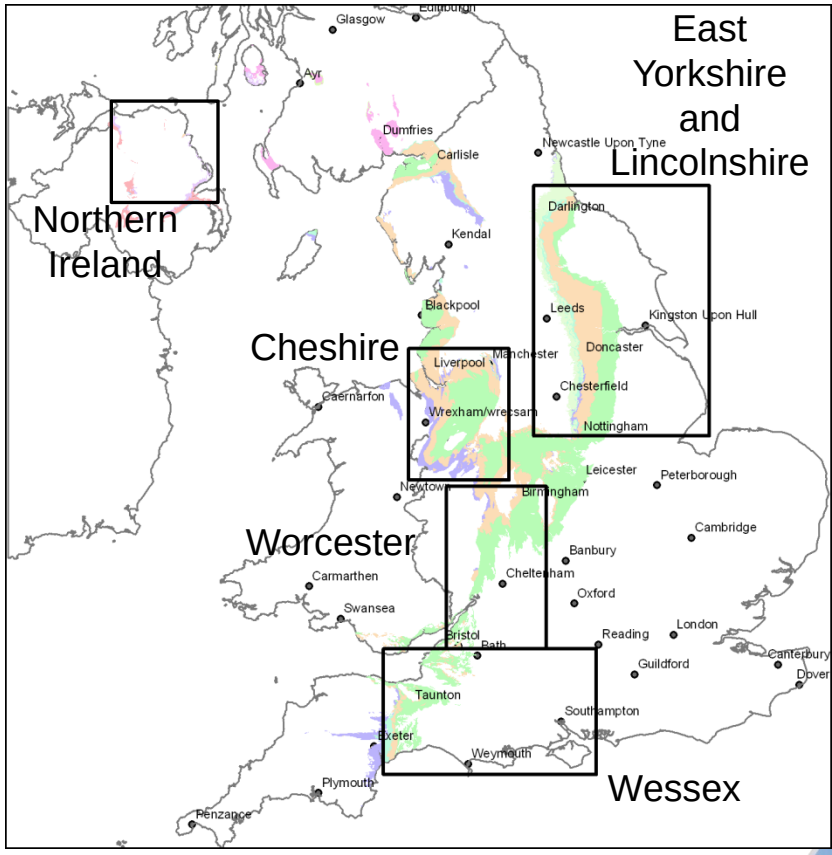
Deep saline aquifers

A geothermal resource calculation for the deep saline aquifers requires

- A geological model of the aquifer (reservoir)
- Maps of the temperature field distribution across and within the aquifer
- Estimates of the hydraulic properties of the aquifer, especially porosity

Permeable, porous rocks are mainly found at depth in the Mesozoic basins. Five main basins in the UK;

- Northern Ireland
- East Yorkshire and Lincolnshire
- Cheshire
- Worcester
- Wessex



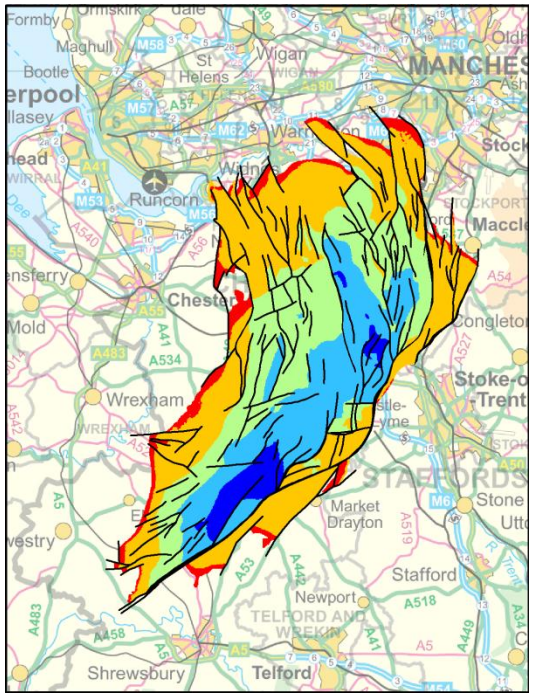
Main aquifers Sherwood Sandstone Group (SSG) and Permian Sandstones.

Deep saline aquifers

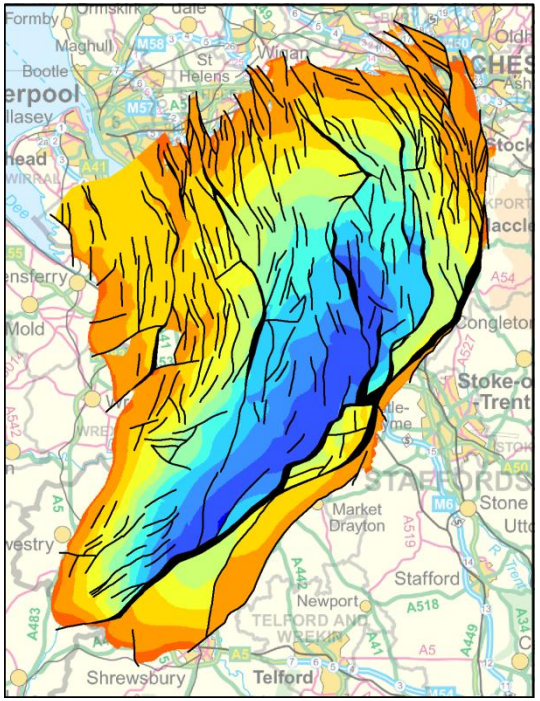
Geological models, Cheshire Basin

Depth (m) from OD

- -118 - 0
- 0 - 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000



Top of Sherwood Sandstone Group



Base of Permian sands

Depth (m) from OD

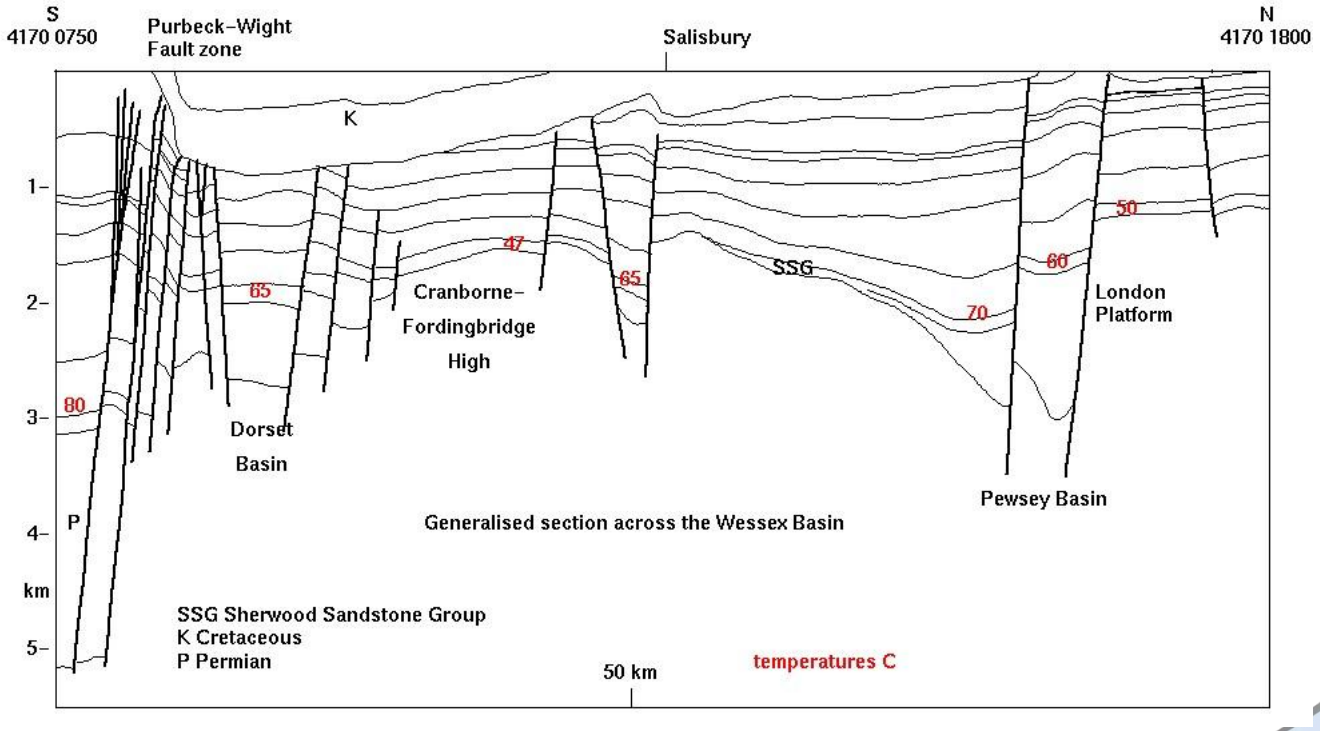
- -520 - -500
- -499 - 0
- 0 - 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 2,500
- 2,500 - 3,000
- 3,000 - 3,500
- 3,500 - 4,000
- 4,000 - 4,500
- 4,500 - 5,000

Deep saline aquifers

Temperature models

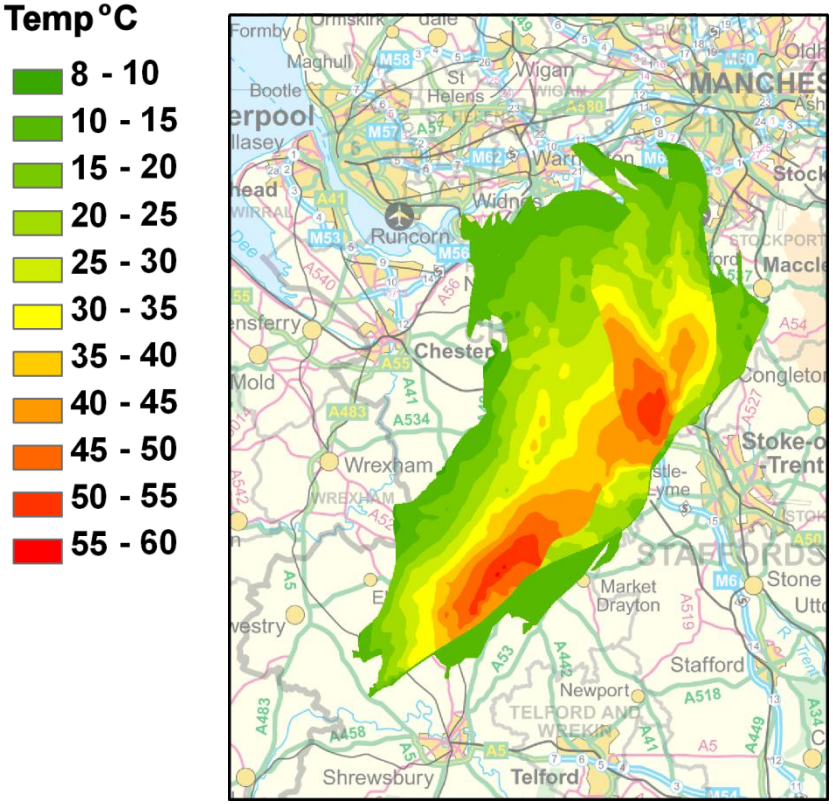
Observed temperatures from UK Geothermal Catalogue.

Calculated temperature field assuming 1-D steady state conductive heat transfer with heat production. Requires models of structure, heat flow, thermal conductivity.

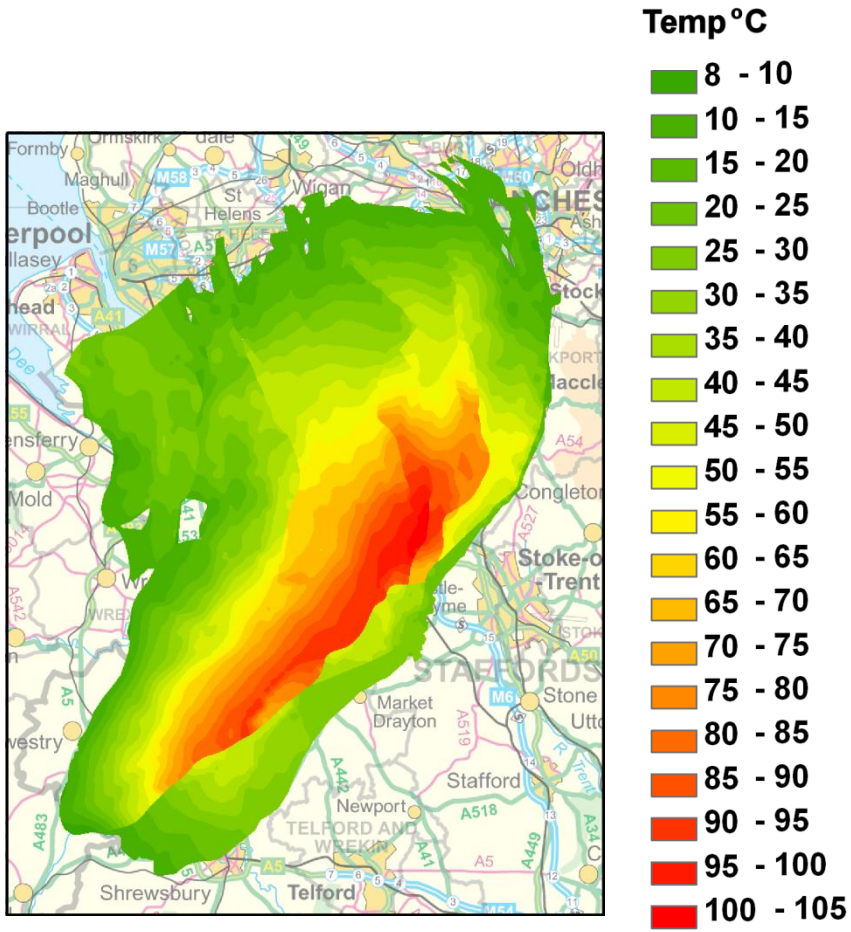


Deep saline aquifers

Calculated temperatures, Cheshire Basin



Top of Sherwood Sandstone Group



Base of Permian sands

Calculated temperature models at the top and base of the principal aquifer formations in the Cheshire Basin

Deep saline aquifers

Porosity has been derived from sonic, neutron and formation density geophysical logs and laboratory measurements.

The geothermal resource is the total heat in place (Ho) based on a simple volume model

$$Ho = [\phi\delta_f c_f + (1-\phi)\delta_m c_m]\, V(T_r - T_0)$$

Where ϕ = fractional porosity
c_f = specific heat of fluid J g^{-1} °C^{-1}
c_m = specific heat of matrix J g^{-1} °C^{-1}
T_0 = temperature of ground surface °C
δ_f = density of pore fluid Mg m^{-3}
δ_m = density of matrix Mg m^{-3}
T_r = temperature of reservoir °C
V = volume of reservoir m^3

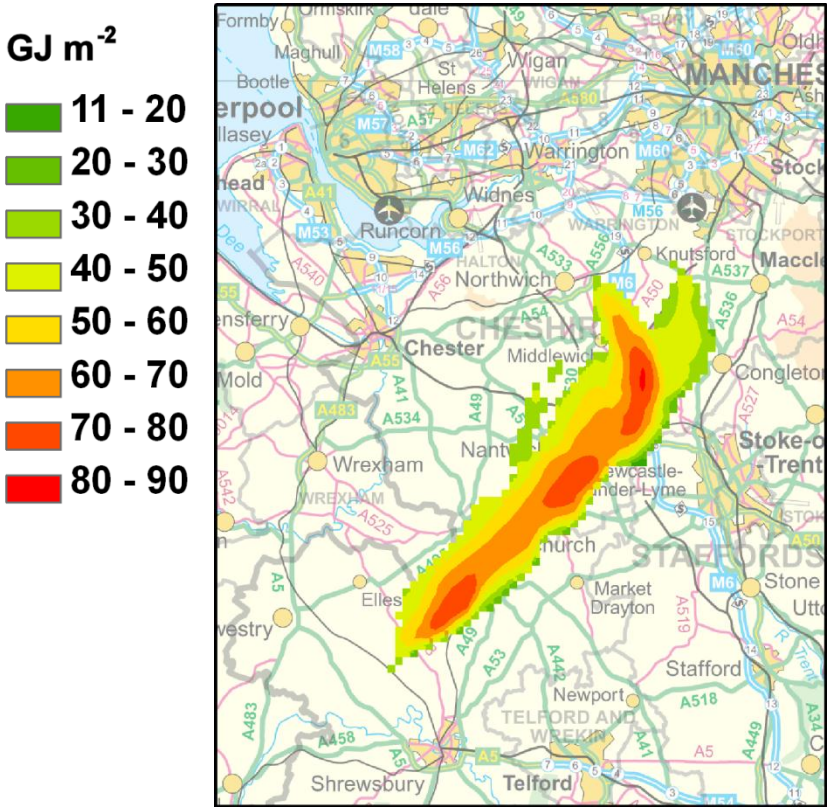
The Identified Resource represents that part of the Geothermal Resource which might be available for development and is related by a function of the hydraulic properties of the aquifer and the method of abstraction (F) and the reject temperature of the disposal fluid (Tj) .

$$Io = Ho.F(T_r - T_j)/(T_r - T_0)$$

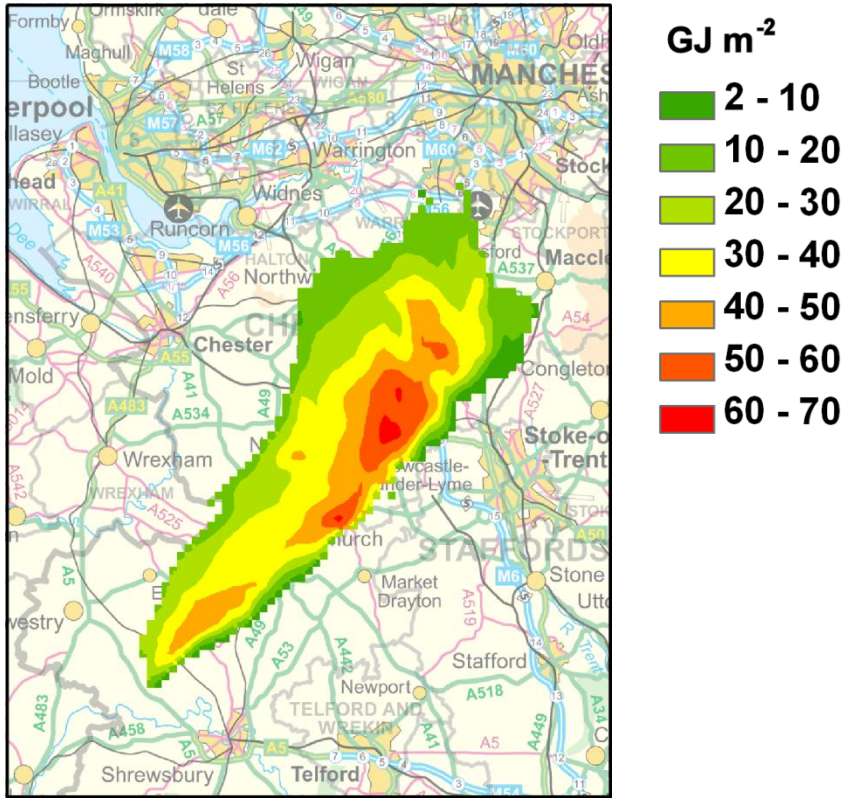
Empirical studies (Paris Basin) suggest F = 0.33 for a doublet and 0.1 for single well abstraction. For the data here Tj = 25 °C, F = 0.33; resource calculations only for reservoir temperatures in excess of 40 °C.

Deep saline aquifers

Geothermal resources, Cheshire Basin



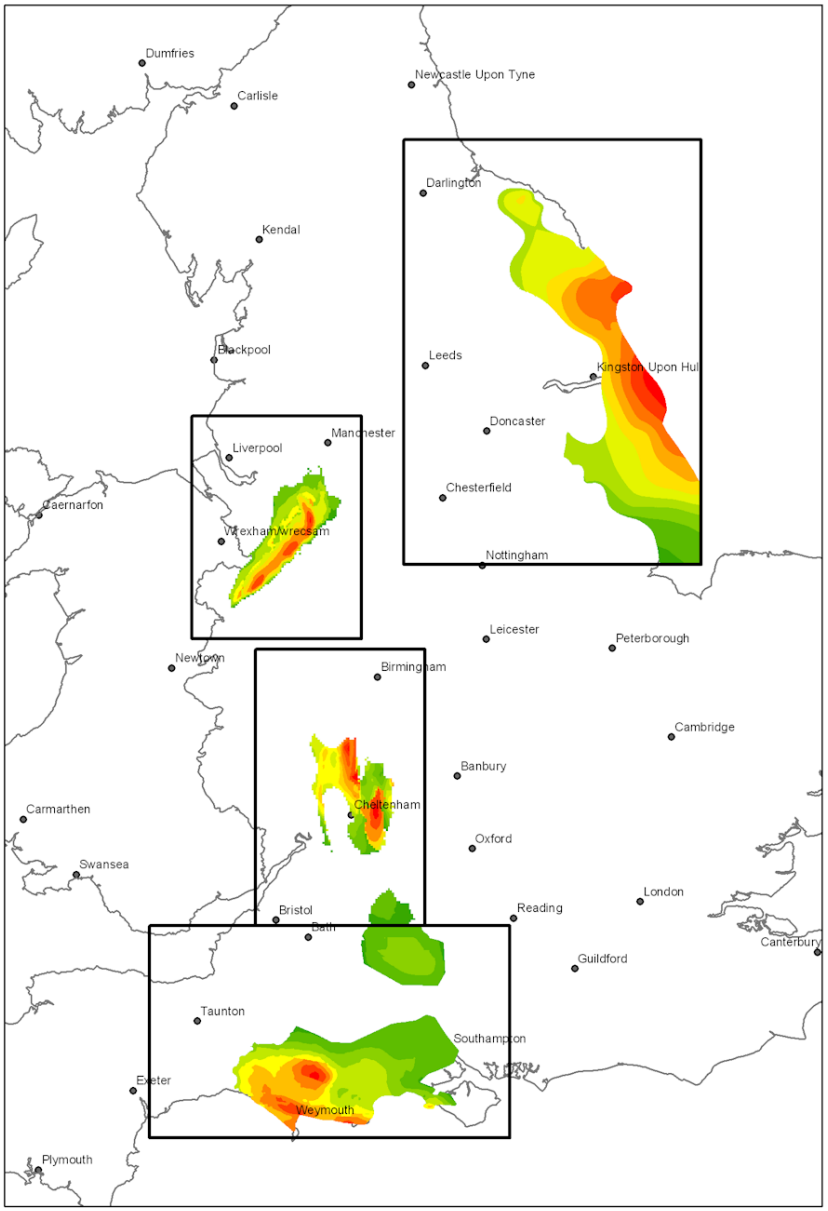
Geothermal resource Sherwood Sandstone Group



Geothermal resource Permian sandstones

The resources are concentrated in the south east of the basin against the main bounding fault and are centred on Crewe.

Geothermal resources



Geothermal resources for the four main sedimentary basins on the UK mainland, based on the 1995 update.

Northern Ireland not shown.

Resources above 40 °C

Summary of UK Low Enthalpy Geothermal Resources 10^{18} J

Basin Resource	Aquifer I-Resource	km^2	G-
East England	SSG Triassic	4827 25	122
Wessex	SSG Triassic	4188 7	27
Worcester	SSG Triassic	500	8 1
	BS Permian	1173 12	60
Cheshire.	SSG Triassic	677 8	36
	CS Permian	1266 9	39
N Ireland	SSG Triassic	1618 8	35

Identified Resources for a reject temperature of 25 °C and a recovery factor of 0.33. SSG Sherwood Sandstone Group; BS Bridgnorth Sandstone; CS Collyhurst Sandstone. 200M barrels oil = 1.2 EJ (EJ = 10^{18} J)

Fluid characteristics

Well	Depth	Thick	Dm	T °C	l/s	g/l
Marchwood	1666-1725	59	4	74	30	103
Southampton	1729-1796	67	<4	76	20	125
Larne	968-1616	648	7	40	-	200
	1823-2264*		441			
<1	65		-			
-						
Cleethorpes	1100-1498	387	>60	60	20	<80
	1865-1891*	26	<2	64	-	220
Prees	1932	-	-	60	-	12#
	2889*	-	-	77	-	50#
Kempsey	2310*	-	-	60	-	26

Triassic sandstones except * Permian sandstones # estimate

Fluids are Na-Cl brines with Na/Cl > seawater and Ca enriched

(Seawater salinity 35 g/l)

Summary

- There is a huge data resource available for deep geothermal including geological, geophysical, geochemical, borehole and temperature data
- Much work has been done to deduce the subsurface distribution of granitic rocks. The granites of southwest England are the most prospective, but further investigations are needed in northern England and Scotland
- A considerable resource has been quantified for the deep saline sedimentary aquifers