Deep Geothermal energy and groundwater in the UK

Jon Busby

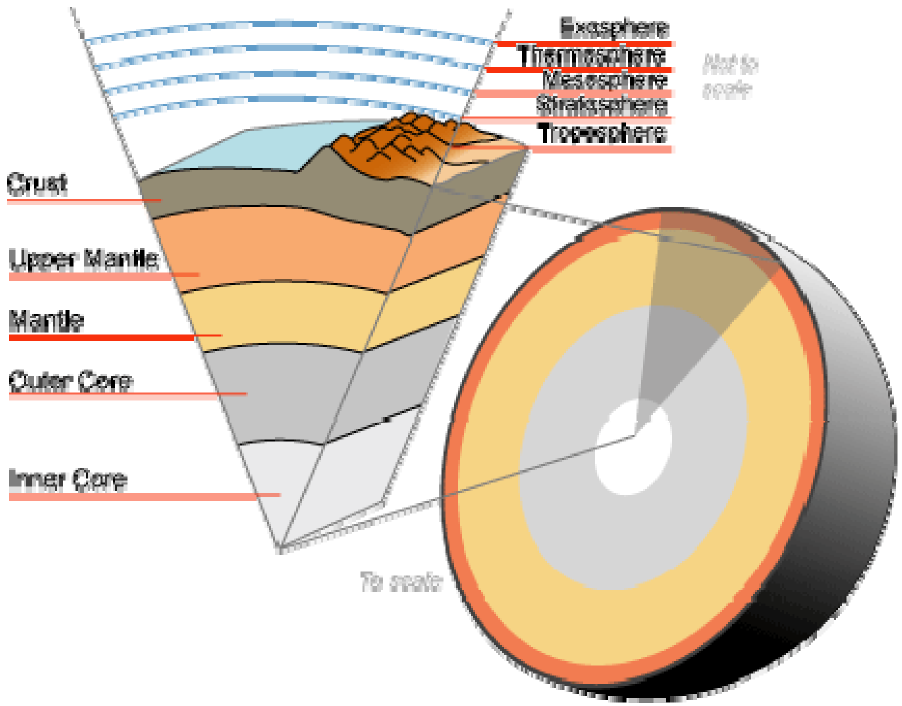
Deep Geothermal energy and groundwater in the UK

Outline

1. UK geothermal
2. Deep saline aquifers
3. Engineered geothermal systems
4. Fractured rock

What is geothermal?

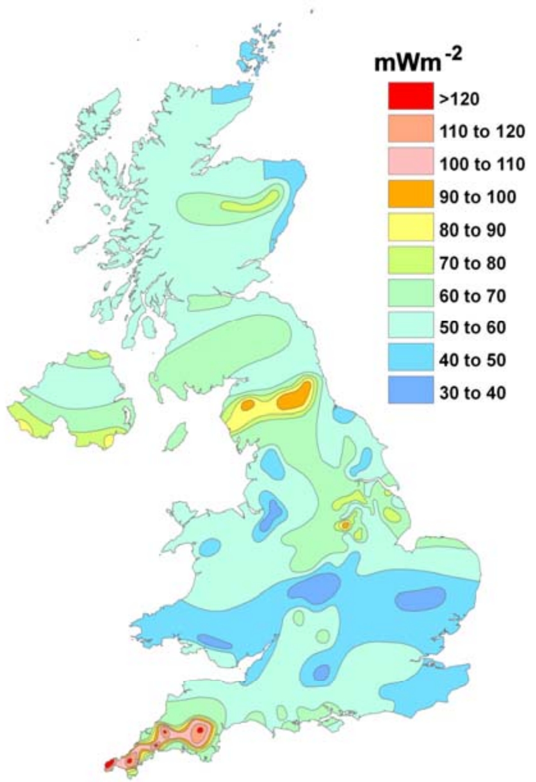
Geothermal energy is the energy stored in the form heat beneath the earth's surface.



Much of the earth's heat, between 45 – 85% is derived from the decay of the radioactive isotopes of Uranium (U^{238}, U^{235}), Thorium (Th^{232}) and Potassium (K^{40}). These are concentrated in the crust and mantle.

The other main source is the primordial energy of planetary accretion. The earth is cooling very slowly, the temperature of the mantle has decreased no more than 300 - 350º C in 3 billion years, remaining at about 4,000º C at its base.

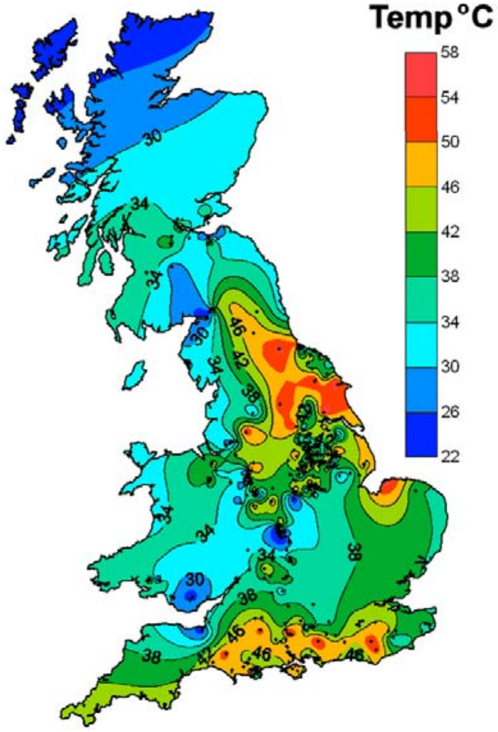
UK geothermal



Heat flow map.

Heat is transferred with water (either groundwater or introduced). Water has

- a high specific heat (4186 J kg^{-1} K^{-1})
- is abundant
- flows readily

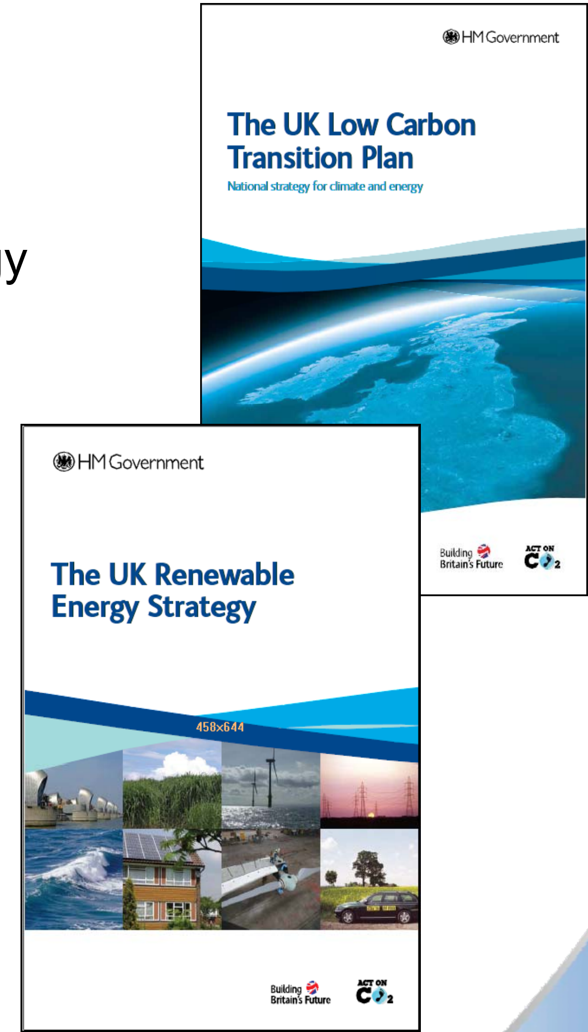


Measured temperatures at 1km below ground level. The black dots indicate the measurement locations.

UK geothermal

Geothermal energy

- Produces no greenhouse gases
- Can contribute towards the UK goal of 15% of energy from renewables by 2020
- Help safeguard security of energy supply



But the UK has no volcanic hydrogeothermal, however

- There is a huge heat resource, exploited via
  - o Ground source heat pumps
  - o Shallow aquifers
  - o Deep saline aquifers
- Micro electricity generation from Engineered Geothermal Systems

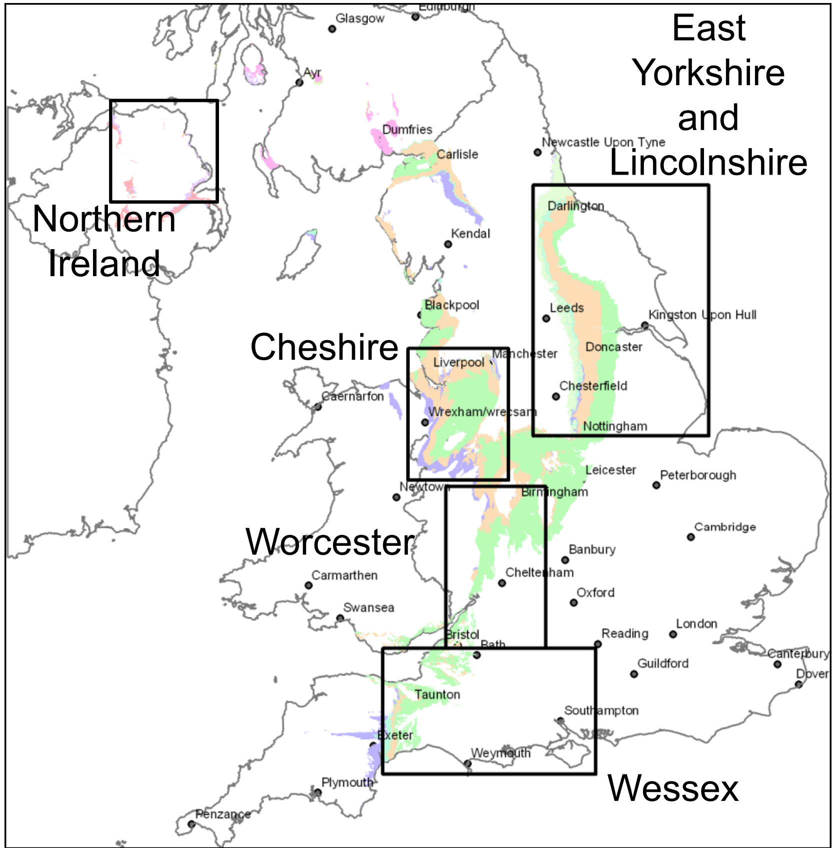
Deep saline aquifers

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

A geothermal resource calculation 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

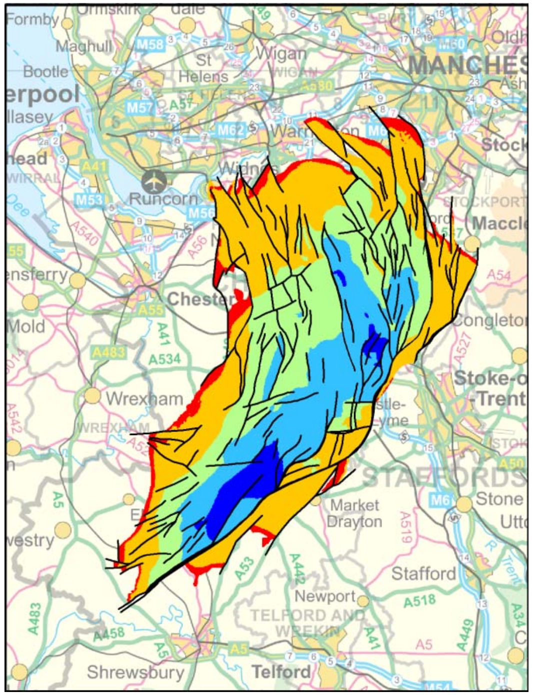


Main aquifers Sherwood Sandstone Group (SSG) and Permian Sandstones.

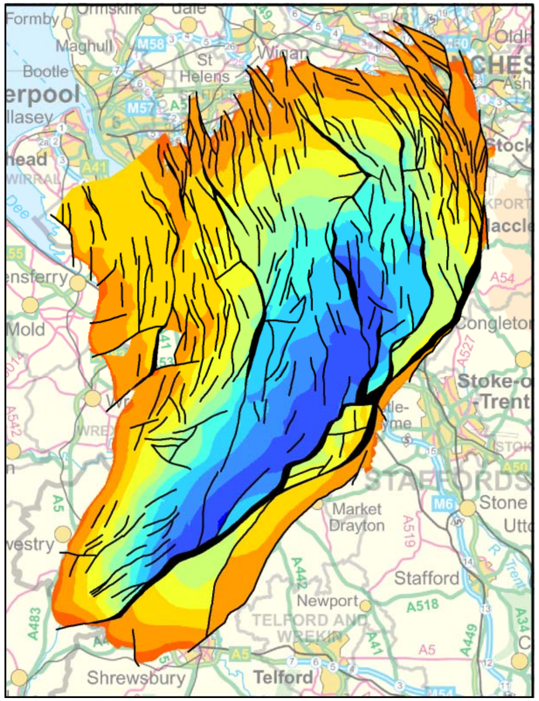
Geological models, Cheshire Basin

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

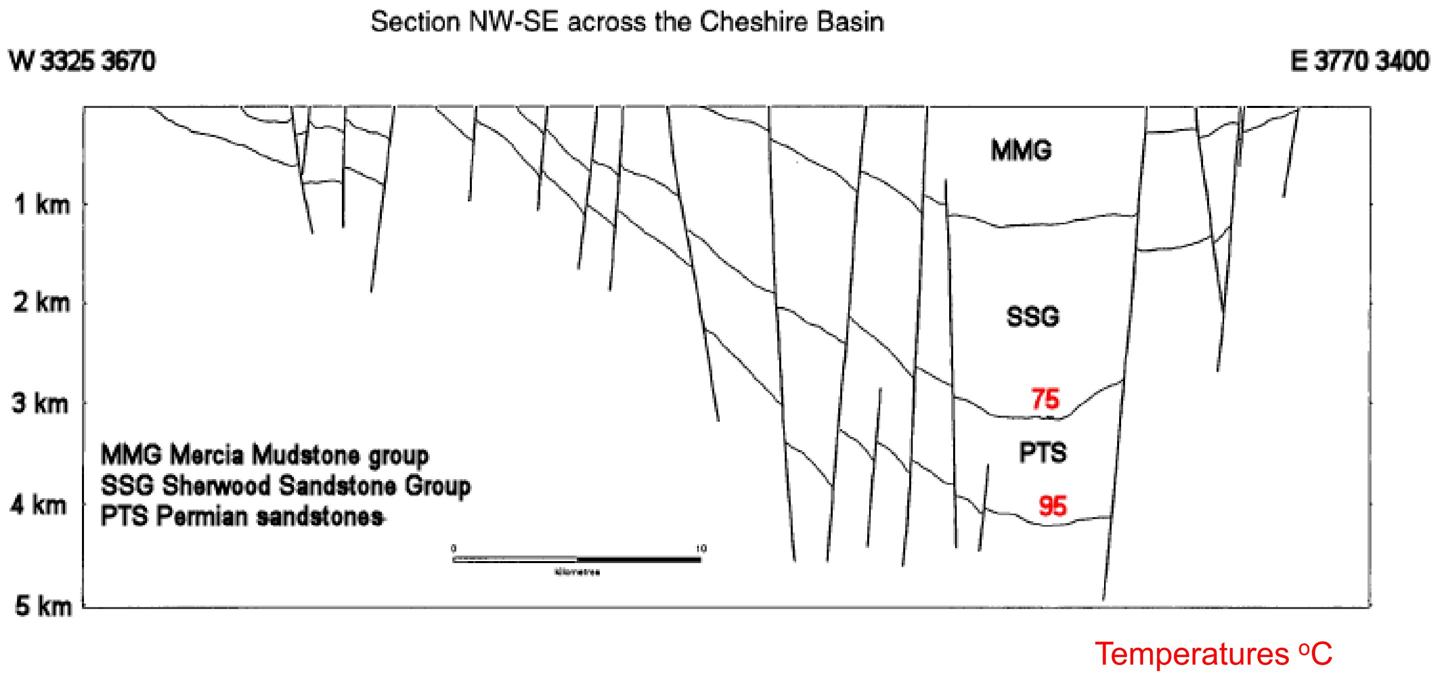
Depth (m) from OD

- -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

Temperature models

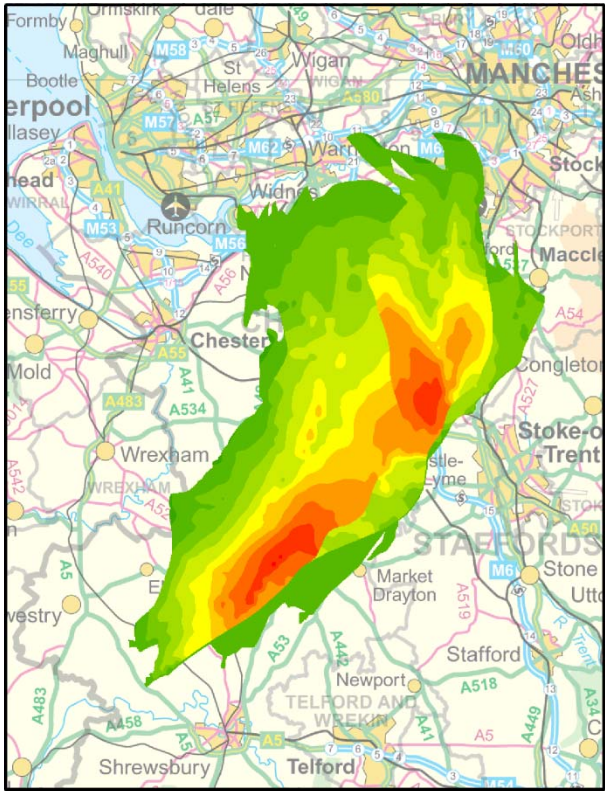
Observed temperatures from UK Geothermal Catalogue.

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

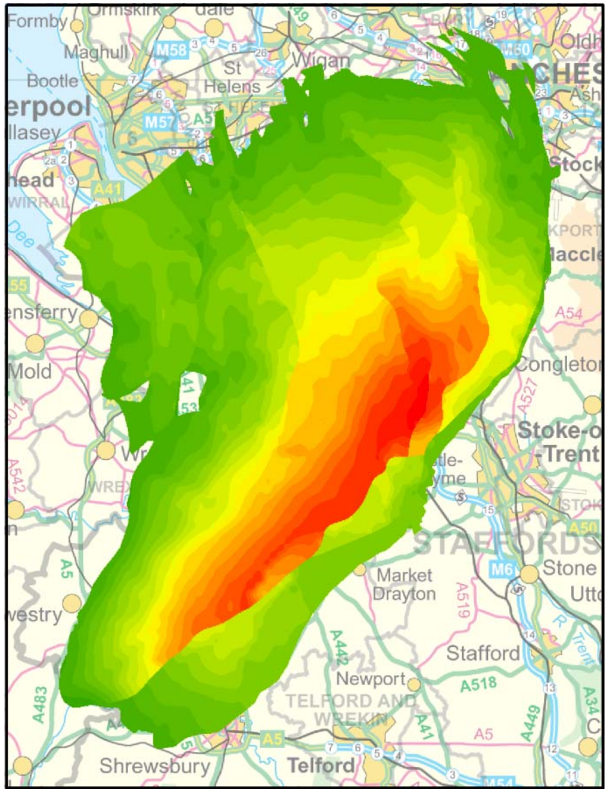


Calculated temperatures, Cheshire Basin

Temp °C
- 8 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50
- 50 - 55
- 55 - 60



Top of Sherwood Sandstone Group



Base of Permian sands

Temp °C
- 8 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50
- 50 - 55
- 55 - 60
- 60 - 65
- 65 - 70
- 70 - 75
- 75 - 80
- 80 - 85
- 85 - 90
- 90 - 95
- 95 - 100
- 100 - 105

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

Hydraulic properties of the aquifer

Porosity, derived from

- Sonic, neutron and formation density geophysical logs
- Laboratory measurements

Permeability

- Primary permeability from interconnected pores
- Secondary permeability is due to fracturing and can be important
- For some formations permeability can be estimated from porosity, but direct borehole measurement (pumping test) is the most reliable

Transmissivity Dm = permeability (mD) x Thickness (m)

- Transmissivity limits can be used to define the productive reservoir.
- Much of reservoir transmissivity is often contained in a few highly permeable zones

Geothermal resources

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

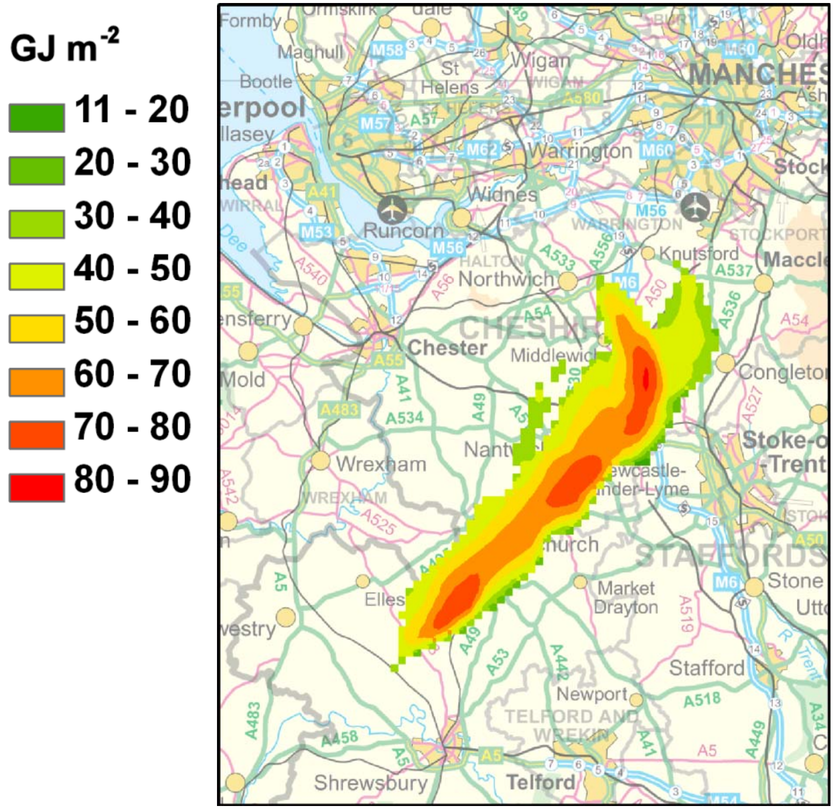
The Identified Resource represents that part of the Geothermal Resource which might be available for development and is related by a function of the hydraulic properties of the aquifer and the method of abstraction (F) and the reject temperature of the disposal fluid (Tj) .

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

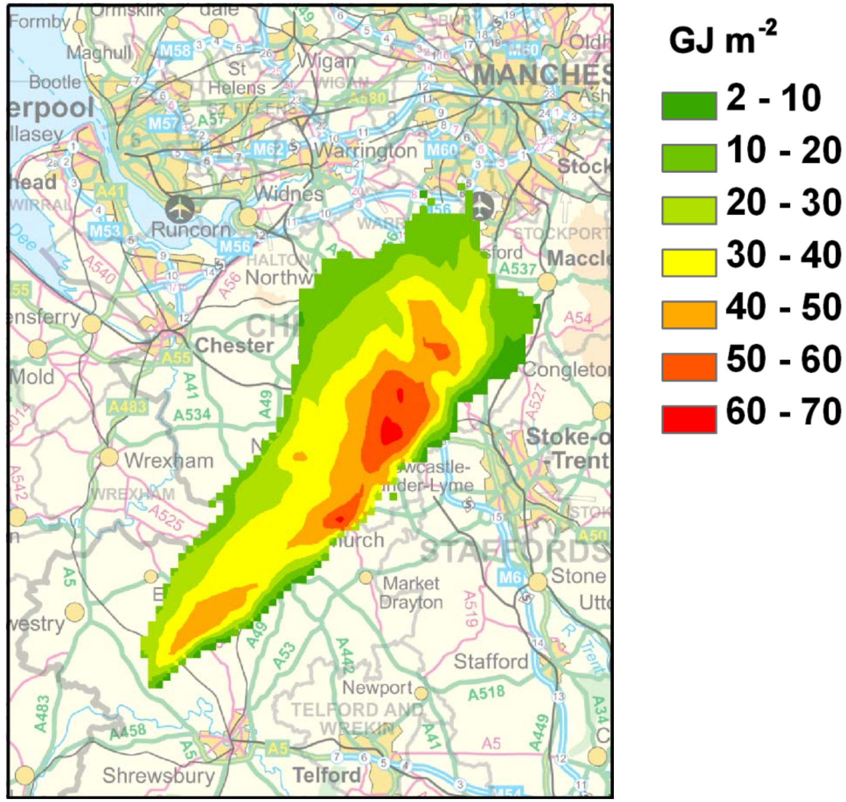
Empirical studies (Paris Basin) suggest F = 0.33 for a doublet and 0.1 for single well abstraction.

For the data here Tj = 25 °C, F = 0.33; resource calculations only for reservoir temperatures in excess of 40 °C.

Geothermal resources, Cheshire Basin



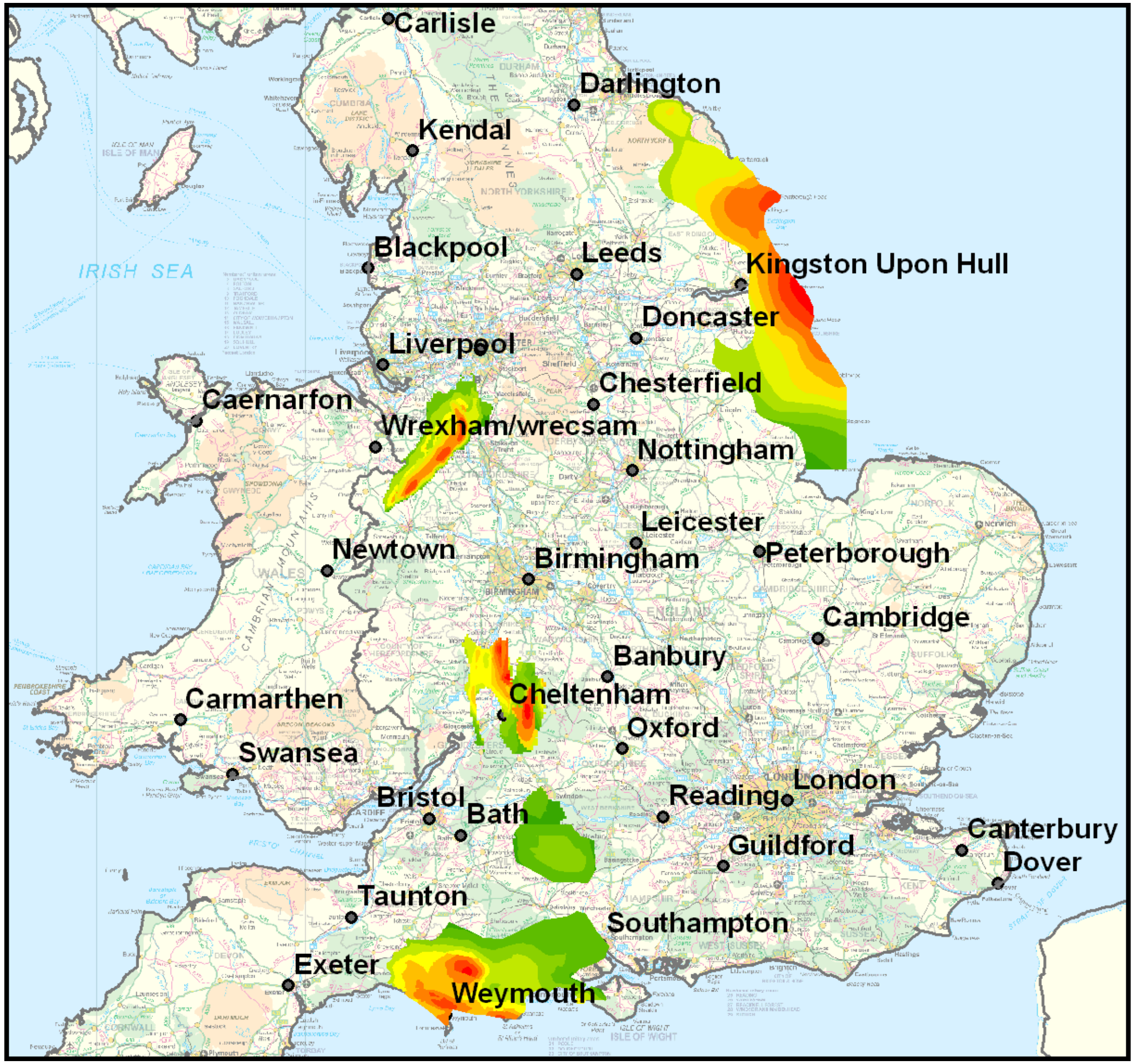
Geothermal resource Sherwood Sandstone Group



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	Aquifer	km^2	G-Resource	I-Resource
East England	SSG Triassic	4827	122	25
Wessex	SSG Triassic	4188	27	7
Worcester	SSG Triassic	500	8	1
	BS Permian	1173	60	12
Cheshire.	SSG Triassic	677	36	8
	CS Permian	1266	39	9
N Ireland	SSG Triassic	1618	35	8
	Totals	**327**	**70**	

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

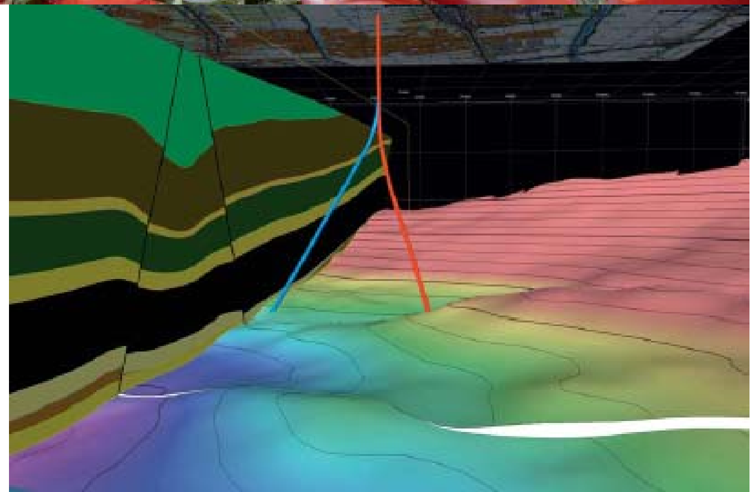
(Seawater salinity 35 g/l)

Deep saline aquifer - Southampton

Brine from a depth of 1.8 km at 76 ºC is pumped to a heat exchanger where the heat is transferred to clean water. The brine, at 28 ºC, is discharged to the sea.

- The geothermal provides 18% of a 30,000 MWt district heating scheme (the rest is gas CHP)
- The scheme contributes major savings in carbon emissions (10Kt yr^{-1})
- It demonstrated that deep geothermal was possible in the UK

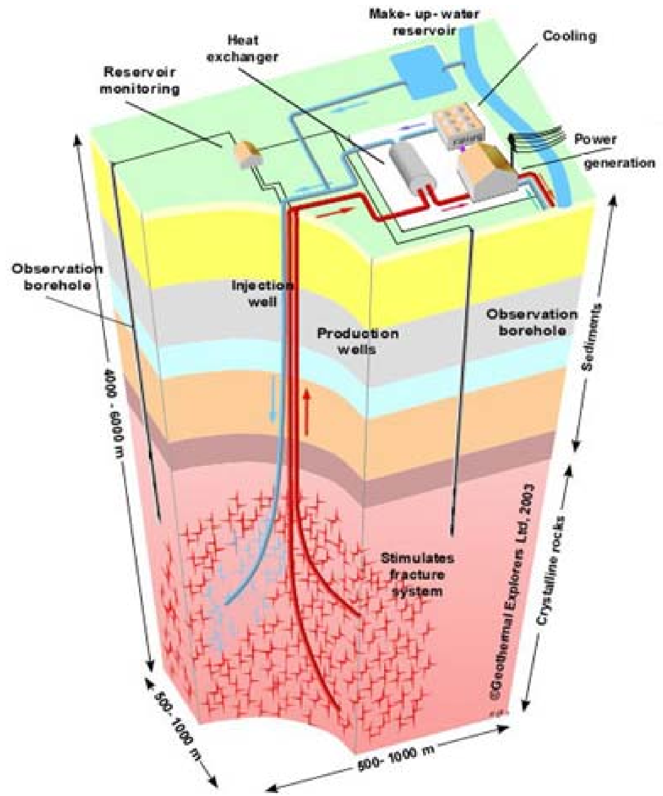
Horticultural heating- Bleiswijk, Holland



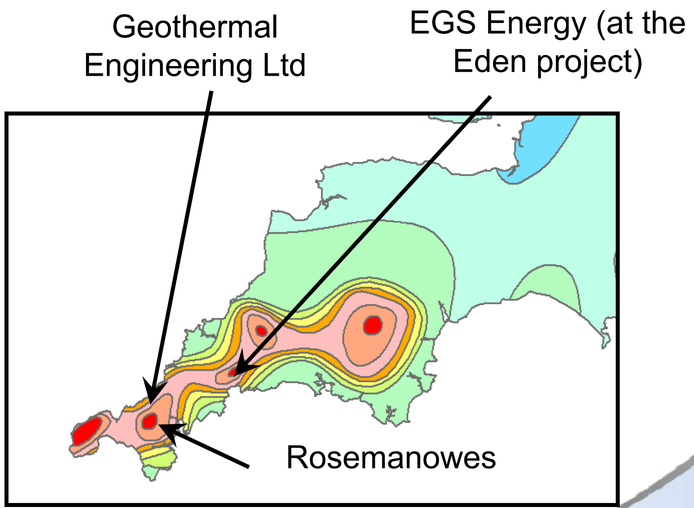
- Doublet drilled into Lower Cretaceous aquifer at 1700 m depth
- Private enterprise, A+G van den Bosch
- Temperature 60 ^{o}C
- Flow rates 130-160 m^3 hr^{-1}
- Saves 3M m^3 of gas per year (700,000 €)
- Expected to pay for itself in 7 years
- Exploration was backed by the Dutch guarantee fund (Ministry for Agriculture and the Productschap Tuinbouw)

Enhanced Geothermal System

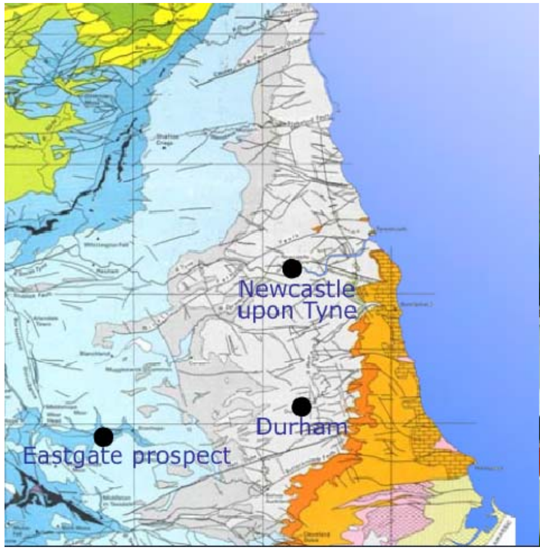
- Well drilled into crystalline basement (4.5-5 km depth)
- Usually aim for higher geothermal gradients associated with high heat producing granites
- Temperatures > 150 ^{o}C
- Fracturing enhanced with hydrofracing
- Second well drilled into fractured reservoir
- Introduced water heated via circulation in the reservoir
- CHP plant generates electricity and supplies heat for district heating



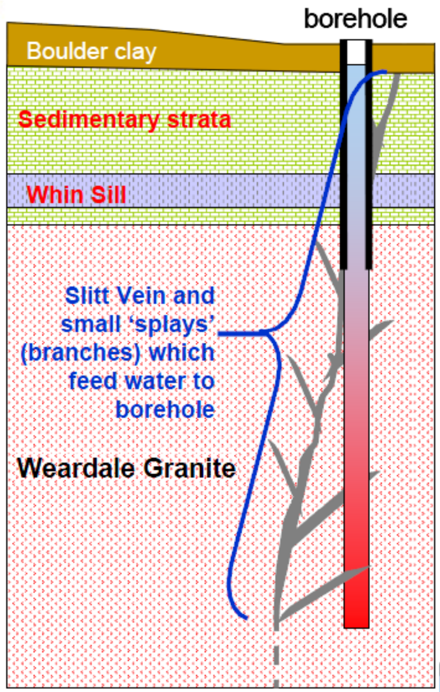
In the UK, in the 1980s, an experiment was carried out at Rosemanowes (Carmenellis granite; 2.6 km, 100 ^{o}C). Today 2 projects are planned in Cornwall; Geothermal Engineering Ltd, 4-5 km depth 10 MWe; EGS Energy, 3-4 km depth, 3 MWe.



Eastgate project Fractured Weardale granite



- Eastgate project led by Newcastle University
- Has targeted the Slitt Vein known from local mining
- Borehole drilled to 995m, temperature 46 ^{o}C
- Major open fissure at 411 m in the granite (27 ^{o}C)
- Flow rates of 50-60 m^3 hr^{-1} associated with the fissure
- Rest water level only 14 m below ground (compared to 150 m at Southampton)
- A second, shallower, injection borehole has now been drilled at Eastgate
- The intention is to use the geothermal resource as one of the renewable options in a new eco village



Summary

- There is a large heat resource at depth
- The deep saline aquifers offer the best prospect to exploit this heat resource
- The largest identified resource is in the SSG of the Eastern England basin that has lower salinity
- Saturated brines can produce problems of precipitation and disposal
- There is still uncertainty in deep reservoir transmissivity
- EGS offers the prospect of geothermal electricity generation
- There may be local opportunities from fractured rock