British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Provision of thermal properties data for ground collector loop design

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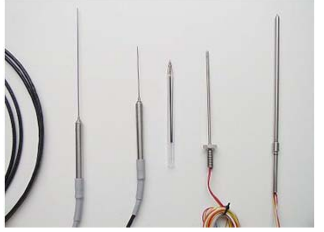
Thermal conductivity

Thermal conductivity is the capacity of a material to conduct or transmit heat

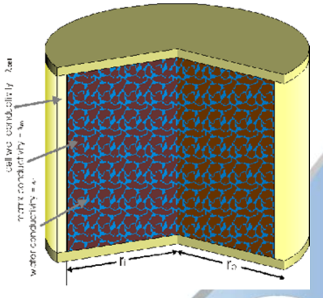
For designing a closed loop ground collector the three key parameters are temperature, thermal conductivity and saturation.

Thermal conductivity can be measured in the laboratory

- Discs cut from cores – Divided bar – steady state method



- Soft material – Needle probe – transient line source method



- Chippings – Pill box – Divided bar

SI unit of measurement $W\ m^{-1}\ K^{-1}$

Thermal conductivity mixing laws

Thermal conductivities, both measured and estimated, often need to be combined.

Horizontally layered (perpendicular to heat flow)

Harmonic mean

$$\frac{1}{\lambda_B} = \frac{1}{Z}\sum_{i=1}^{n}\frac{z_i}{\lambda_i}$$

λ_B = mean thermal conductivity

λ_i = thermal conductivity of the ith bed

z_i = thickness of the ith bed

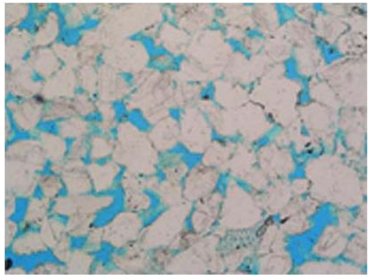
Z = total thickness of sequence

Vertically layered (parallel to heat flow)

Arithmetic mean

$$\lambda_B = \frac{1}{Z}\sum_{i=1}^{n} z_i \lambda_i$$

Randomly orientated and distributed



Geometric mean

$$\lambda_B = \prod_{i=1}^{n} \lambda_i^{\phi_i}$$

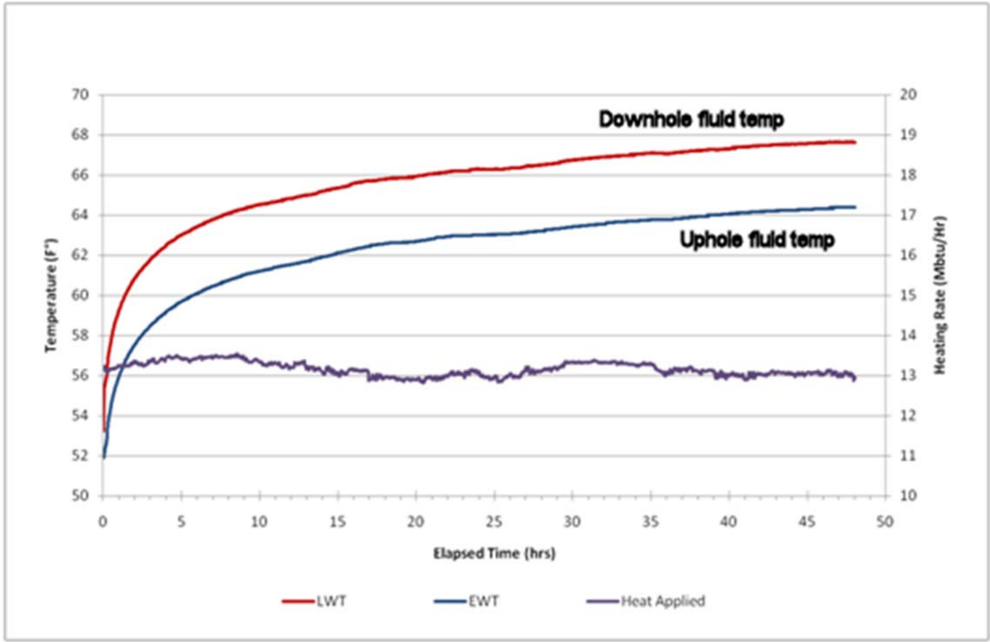
λ_B = mean thermal conductivity

λ_i = thermal conductivity of the ith component

θ_i = fractional proportion of the ith component

Thermal response test

Warm water circulated through a closed vertical loop with the uphole and downhole temperatures measured. From the evolution of temperature with time the thermal conductivity and borehole resistance are calculated.

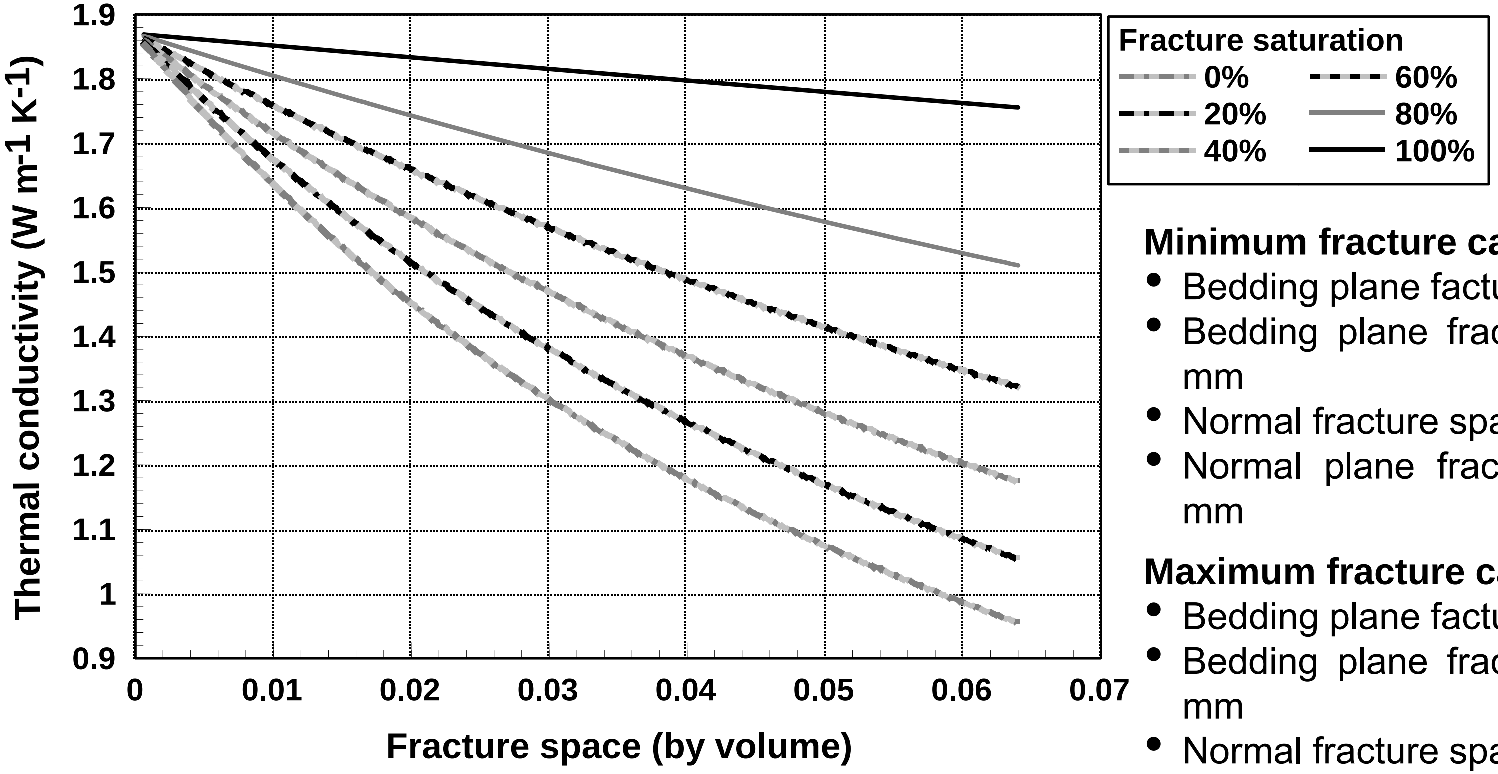


Advantage the in-situ thermal conductivity for the rock mass over the length of the borehole is measured

Disadvantage expensive, only applicable to large schemes

Theoretical calculation - chalk

Chalk matrix porosity 34%; thermal conductivity 1.87 W m^{-1} K^{-1}



Minimum fracture case

- Bedding plane facture spacing = 1 m
- Bedding plane fracture aperture = 0.1 mm
- Normal fracture spacing = 1 m
- Normal plane fracture aperture = 0.5 mm

Maximum fracture case

- Bedding plane facture spacing = 0.05 m
- Bedding plane fracture aperture = 0.7 mm
- Normal fracture spacing = 0.1 m
- Normal plane fracture aperture = 5.0 mm

Chalk matrix is assumed to comprise Calcite, Smectite and saturated pores. Bedding plane fractures incorporated with a harmonic mean, normal fractues with an arithmetic mean.

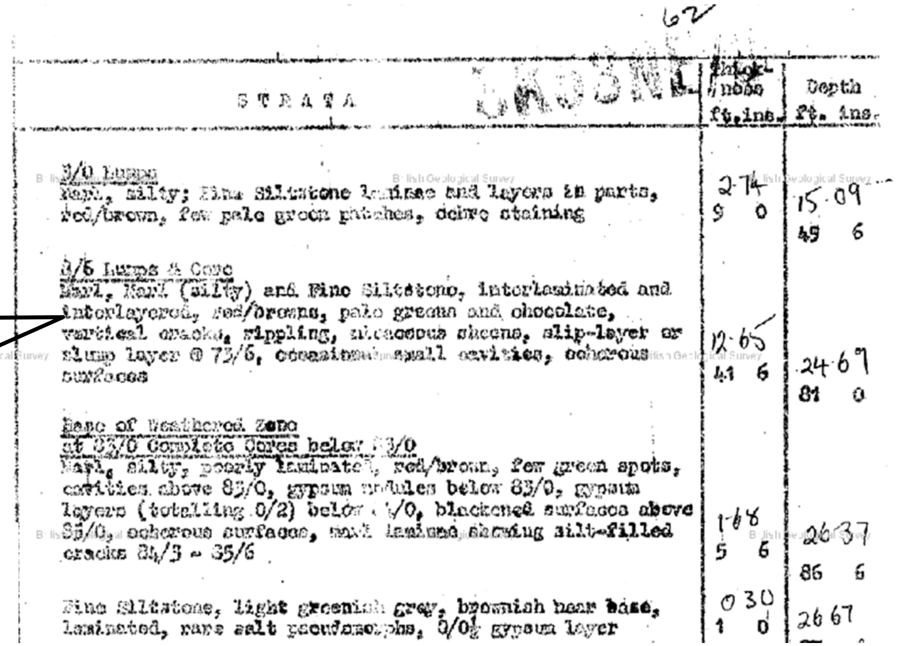
New standards

New standards (MIS 3005) require a robust value of thermal conductivity for the ground collector loop design. This is used in look up tables to calculate maximum power extracted per unit length of borehole or area of a horizontal ground array.

Can this be obtained from viewing publicly available borehole scans?

www.bgs.ac.uk/data/boreholescans/home.html

Marl, Marl (silty) and Fine Siltstone, interlaminated and interlayered, red/browns, pale green and chocolate, vertical cracks, rippling, micaceous sheens, slip layer or slump layer @ 73/6, containing small cavities, ocherous surfaces



STRATA	Thickness ft. ins.	Depth ft. ins.
3/0 Lumps Marl, silty; Fine Siltstone laminae and layers in parts, red/brown, few pale green patches, ochre staining	9 0	49 6
3/6 Lumps & Core Marl, Marl (silty) and Fine Siltstone, interlaminated and interlayered, red/browns, pale greens and chocolate, vertical cracks, rippling, micaceous sheens, slip-layer or slump layer @ 73/6, occasional small cavities, ochreous surfaces	41 6	81 0
Base of Weathered Zone at 83/0 Complete Cores below 83/0 Marl, silty, poorly laminated, red/brown, few green spots, cavities above 83/0, gypsum nodules below 83/0, gypsum layers (totalling 0/2) below [illegible]/0, blackened surfaces above 85/0, ochreous surfaces, marl laminae showing silt-filled cracks 84/3 - 85/6	5 6	86 6
Fine Siltstone, light greenish grey, brownish near base, laminated, rare salt pseudomorphs, 0/0½ gypsum layer	1 0	

	Type of rock	Thermal conductivity (/W/mK)		
		Min	Max	Recommended
Unconsolidated rock	Sand, dry	0.3	0.8	0.4
	Gravel, dry	0.4	0.5	0.4
	Peat, soft lignite	0.2	0.7	0.4
	Clay/silt, dry	0.4	1.0	0.5
	Clay/silt, water saturated	0.9	2.3	1.7
	Gravel, water saturated	1.6	2.0	1.8
	Claystone, siltstone	1.1	3.5	2.2
	Sand, water saturated	1.5	4.0	2.4
Solid Sediments	Hard coal	0.3	0.6	0.4
	Gypsum	1.3	2.8	1.6
	Marl	1.5	3.5	2.1
	Sandstone	1.3	5.1	2.3
	Conglomerates	1.3	5.1	2.3
	Limestone	2.5	4.0	2.8
	Dolomite	2.8	4.3	3.2
	Anhydrite	1.5	7.7	4.1
	Salt	5.3	6.4	5.4

DRAFT

......and generalised tables of thermal conductivity based on rock type (e.g. VDI 4640: 2010)

Tables of UK thermal conductivities

BGS has also published tables of UK thermal conductivities based on formation and rock type.

System	Formation	Lithology	Code	nk	cond	se
Palaeogene						
	Barton Beds	SMST	109	10	2.12	0.06
		MDST	109	2	1.46	0.05
	Bracklesham Beds	SMST	109	14	2.20	0.16
		MDST	109	4	1.58	0.01
	London Clay	SMST	108	5	2.45	0.07
	Reading Beds	SMST	107	4	2.33	0.04
		MDST	107	10	1.63	0.11
Cretaceous						
	Chalk	CHLK	106	41	1.79	0.54
	Upper Greensand	SDST	105	18	2.66	0.19
	Gault	SMST	105	32	2.32	0.04
		MDST	105	4	1.67	0.11
	Hastings Beds	SLST.	102	2	2.01	
		SLCL	102	3	1.26	
Jurassic						
	Kimmeridge Clay	MDST	99	58	1.51	0.09
	Ampthill Clay	MDST	98	60	1.29	0.03
	Oxford Clay	MDST	97	27	1.56	0.09
	Kellaways	MDST	97	21	1.52	0.03
	Cornbrash	LMST	96	5	2.29	0.17
	Forest Marble	MDST	95	37	1.80	0.07
	Frome Clay	MDST	95	15	1.72	1.10
	Fullers Earth	MDST	95	47	1.95	0.05
	Upper Lias	SDST	93	13	2.87	0.12
		MDST	93	11	1.27	0.03
		SLMD	93	11	2.22	1.10

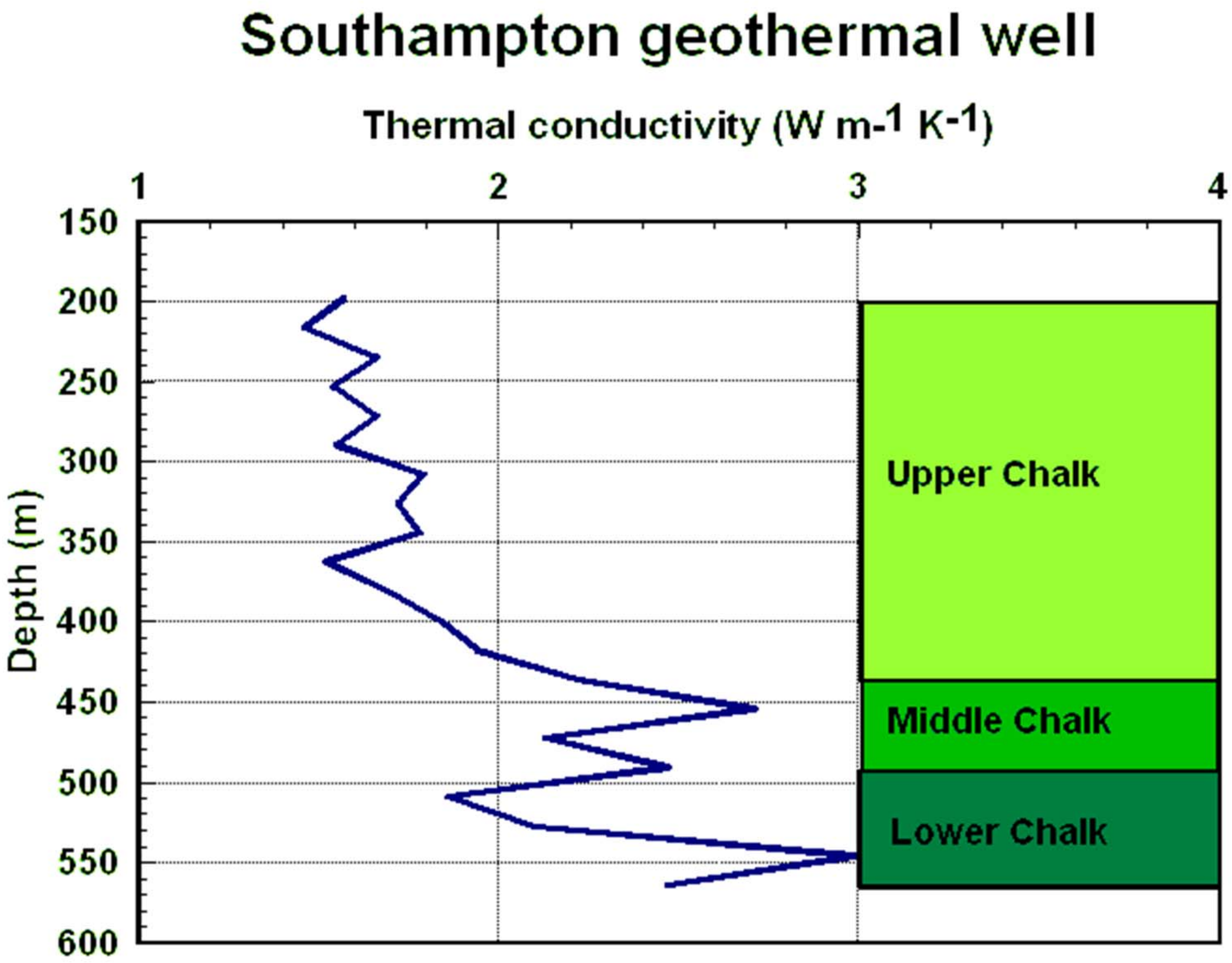
Part of table from Rollin, 1987, Catalogue of geothermal data for the land area of the United Kingdom. Third revision: April 1987. Investigation of the geothermal potential of the UK, British Geological Survey.

Produced as part of the Geothermal Energy Programme

But, where does the BGS data come from?

Southampton (441560 112020) Hampshire

Thermal conductivity measurements needle probe



<u>Harmonic mean thermal conductivity ($W\ m^{-1}\ K^{-1}$)</u>

Chalk = 1.86

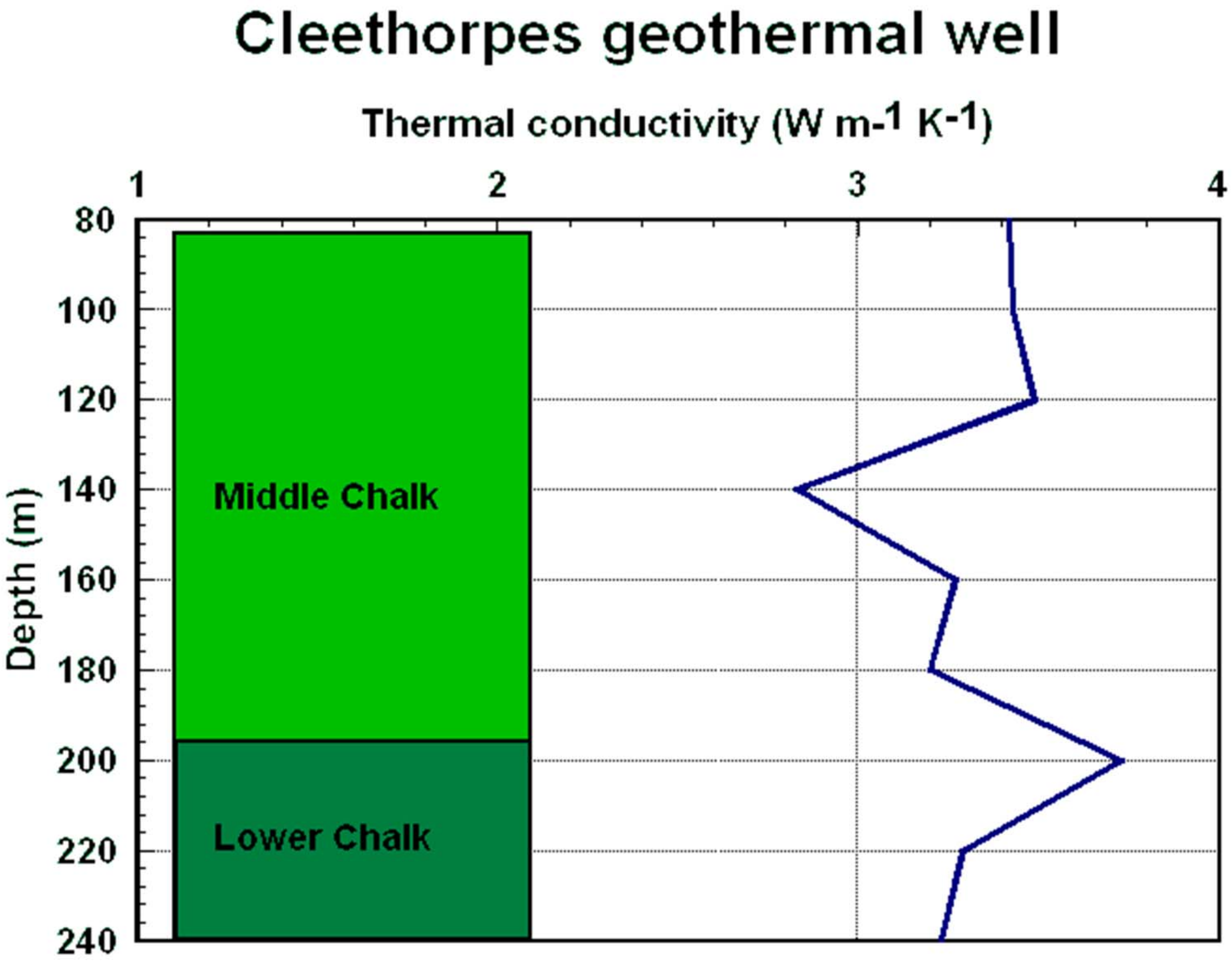
Upper Chalk = 1.69

Middle Chalk = 2.36

Lower Chalk = 2.28

Cleethorpes (530240 407090) Lincolnshire

Thermal conductivity measurements pill box divided bar



Harmonic mean thermal conductivity ($W\ m^{-1}\ K^{-1}$)

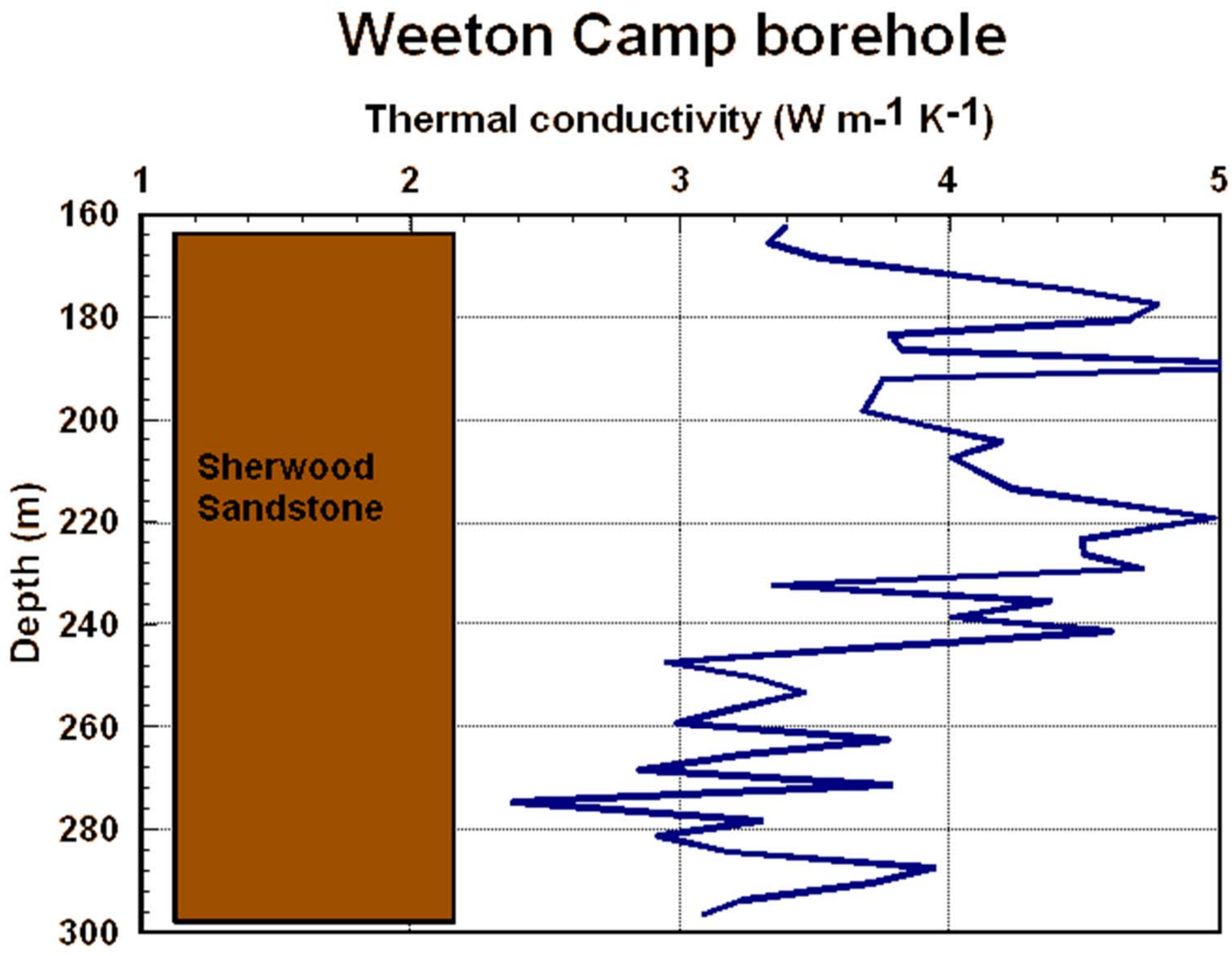
Chalk = 3.3

Middle Chalk = 3.26

Lower Chalk = 3.4

Weeton Camp (338900 435900) Lancashire

Thermal conductivity measurements pill box divided bar



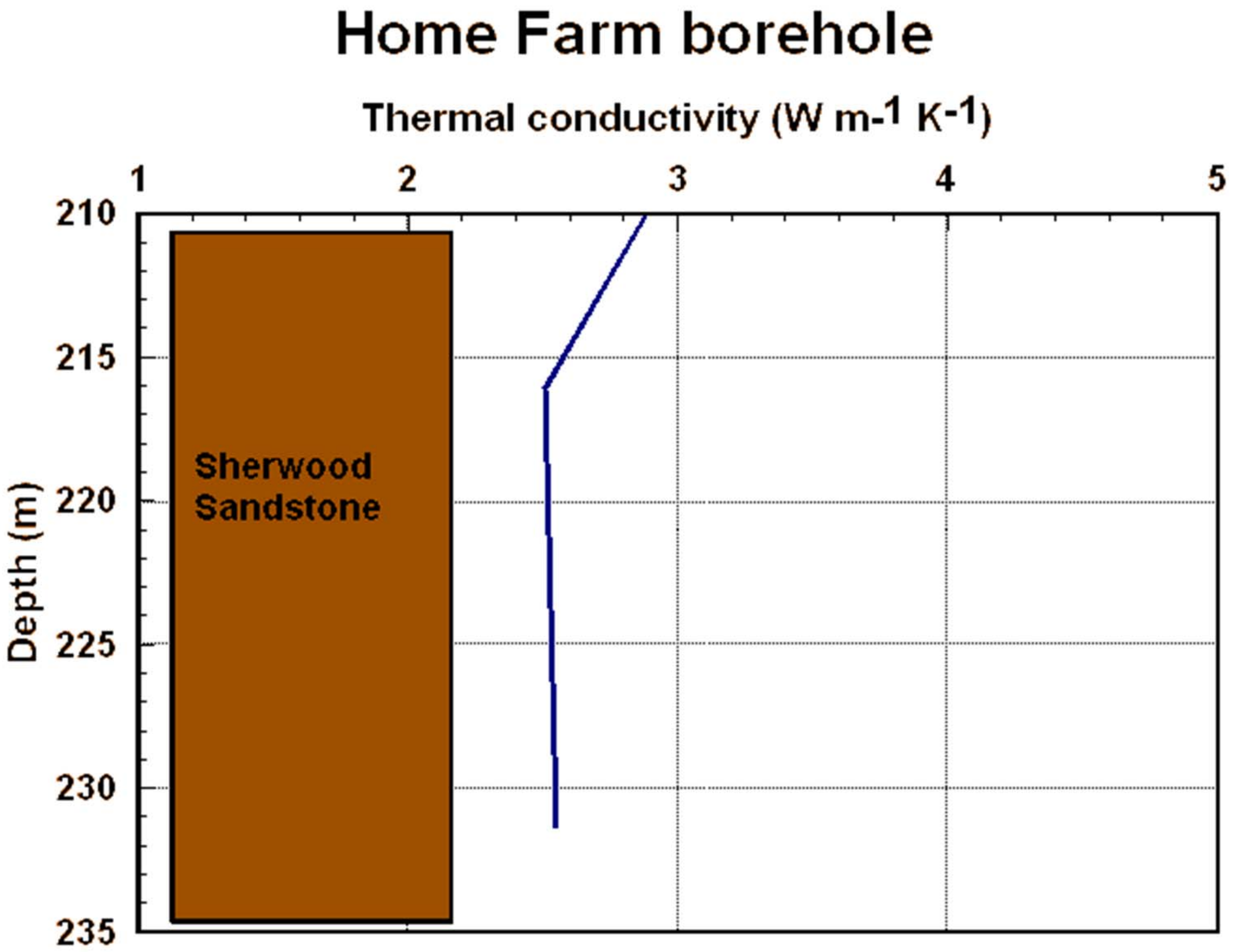
<u>Harmonic mean thermal conductivity</u>

Sherwood Sandstone (sandstone facies)

3.68 W m^{-1} K^{-1}

Home Farm (443200 273100) Warwickshire

Thermal conductivity measurements divided bar



Harmonic mean thermal conductivity

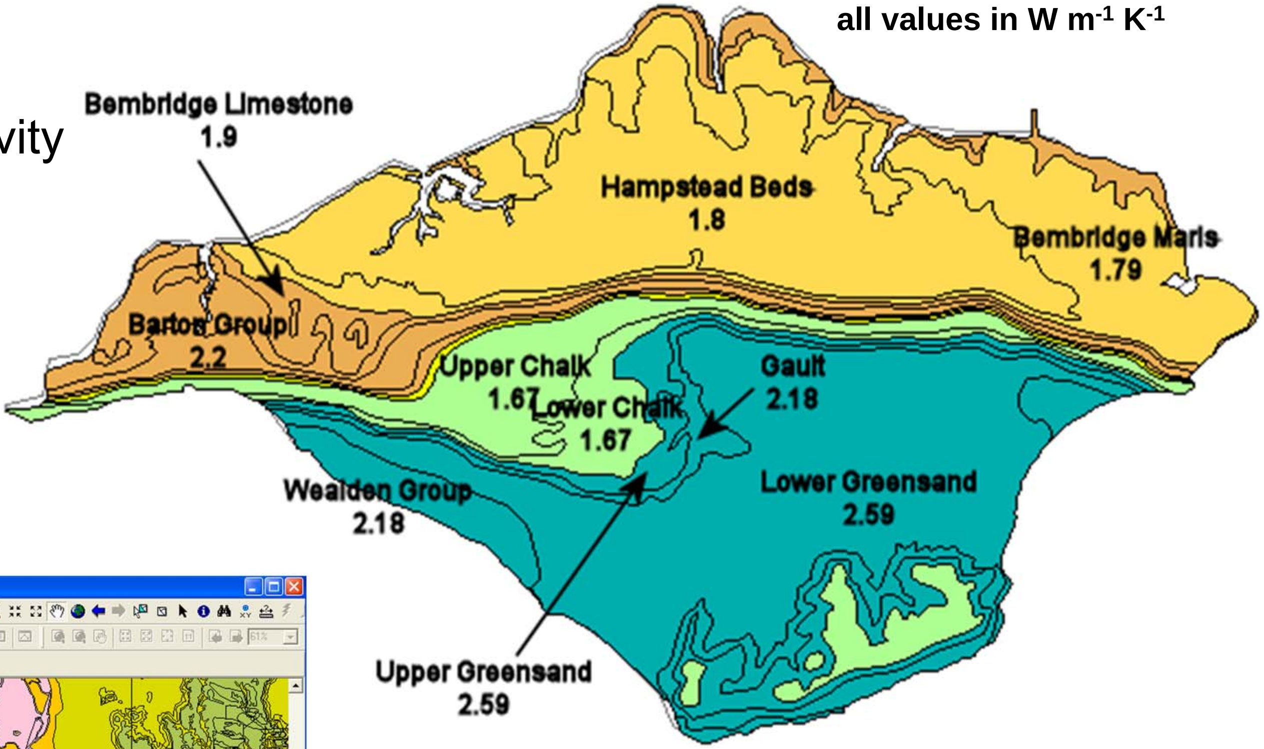
Sherwood Sandstone (sandstone facies)

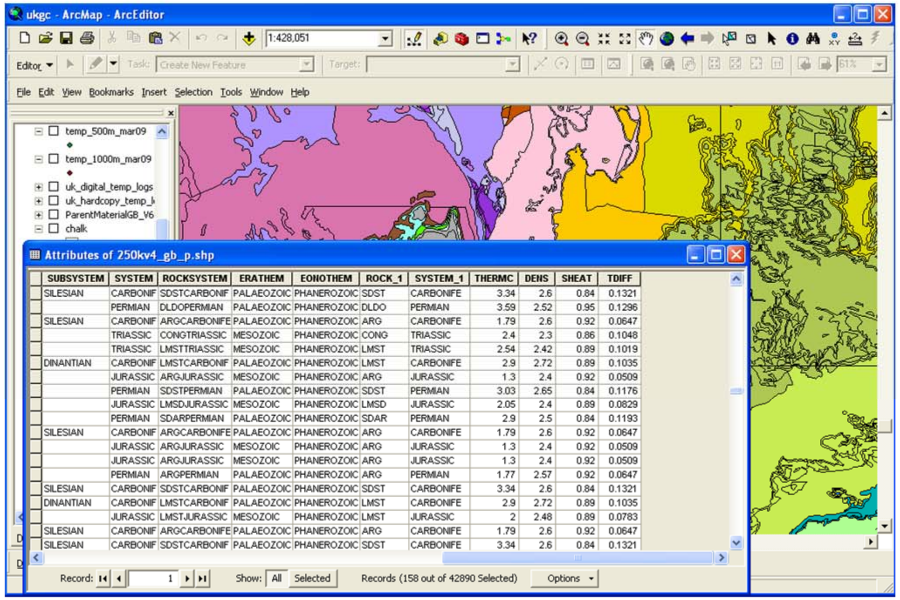
2.58 W m^{-1} K^{-1}

Attribution of 1:250000 geology

all values in W m^{-1} K^{-1}

The 4727 thermal conductivity measurements have been used to generate formation averages





SUBSYSTEM	SYSTEM	ROCKSYSTEM	ERATHEM	EONOTHEM	ROCK_1	SYSTEM_1	THERMC	DENS	SHEAT	TDIFF
SILESIAN	CARBONIF	SDSTCARBONIF	PALAEOZOIC	PHANEROZOIC	SDST	CARBONIFE	3.34	2.6	0.84	0.1321
	PERMIAN	DLDOPERMIAN	PALAEOZOIC	PHANEROZOIC	DLDO	PERMIAN	3.59	2.52	0.95	0.1296
SILESIAN	CARBONIF	ARGCARBONIFE	PALAEOZOIC	PHANEROZOIC	ARG	CARBONIFE	1.79	2.6	0.92	0.0647
	TRIASSIC	CONGTRIASSIC	MESOZOIC	PHANEROZOIC	CONG	TRIASSIC	2.4	2.3	0.86	0.1048
	TRIASSIC	LMSTTRIASSIC	MESOZOIC	PHANEROZOIC	LMST	TRIASSIC	2.54	2.42	0.89	0.1019
DINANTIAN	CARBONIF	LMSTCARBONIF	PALAEOZOIC	PHANEROZOIC	LMST	CARBONIFE	2.9	2.72	0.89	0.1035
	JURASSIC	ARGJURASSIC	MESOZOIC	PHANEROZOIC	ARG	JURASSIC	1.3	2.4	0.92	0.0509
	PERMIAN	SDSTPERMIAN	PALAEOZOIC	PHANEROZOIC	SDST	PERMIAN	3.03	2.65	0.84	0.1176
	JURASSIC	LMSDJURASSIC	MESOZOIC	PHANEROZOIC	LMSD	JURASSIC	2.05	2.4	0.89	0.0829
	PERMIAN	SDARPERMIAN	PALAEOZOIC	PHANEROZOIC	SDAR	PERMIAN	2.9	2.5	0.84	0.1193
SILESIAN	CARBONIF	ARGCARBONIFE	PALAEOZOIC	PHANEROZOIC	ARG	CARBONIFE	1.79	2.6	0.92	0.0647
	JURASSIC	ARGJURASSIC	MESOZOIC	PHANEROZOIC	ARG	JURASSIC	1.3	2.4	0.92	0.0509
	JURASSIC	ARGJURASSIC	MESOZOIC	PHANEROZOIC	ARG	JURASSIC	1.3	2.4	0.92	0.0509
	PERMIAN	ARGPERMIAN	PALAEOZOIC	PHANEROZOIC	ARG	PERMIAN	1.77	2.57	0.92	0.0647
SILESIAN	CARBONIF	SDSTCARBONIF	PALAEOZOIC	PHANEROZOIC	SDST	CARBONIFE	3.34	2.6	0.84	0.1321
DINANTIAN	CARBONIF	LMSTCARBONIF	PALAEOZOIC	PHANEROZOIC	LMST	CARBONIFE	2.9	2.72	0.89	0.1035
	JURASSIC	LMSTJURASSIC	MESOZOIC	PHANEROZOIC	LMST	JURASSIC	2	2.48	0.89	0.0783
SILESIAN	CARBONIF	ARGCARBONIFE	PALAEOZOIC	PHANEROZOIC	ARG	CARBONIFE	1.79	2.6	0.92	0.0647
SILESIAN	CARBONIF	SDSTCARBONIF	PALAEOZOIC	PHANEROZOIC	SDST	CARBONIFE	3.34	2.6	0.84	0.1321

..... and then extrapolated with “expert knowledge” to attribute the 1:250k geology

Ground conditions

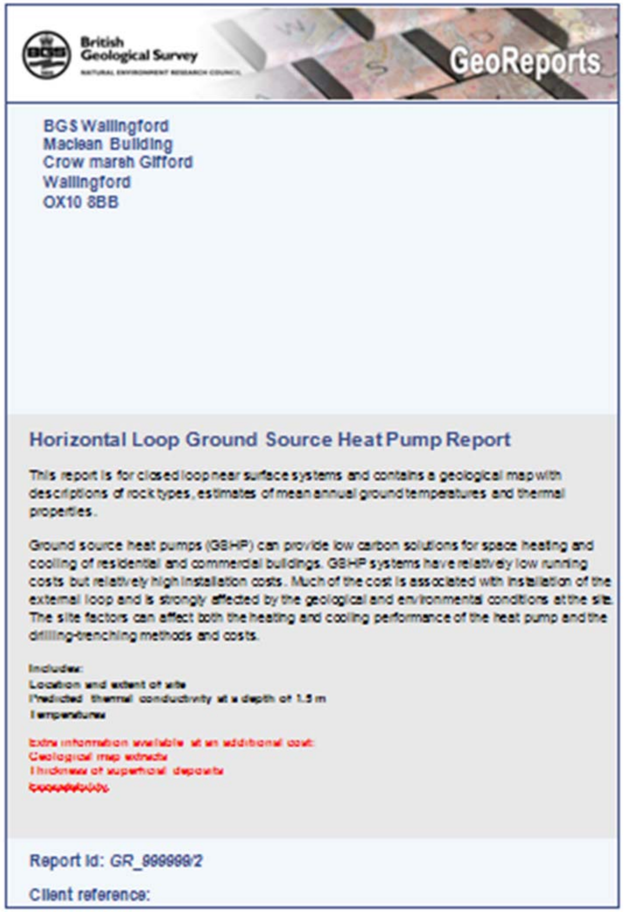
Site specific information

Reports of relevant parameters can be compiled for a site based on a post code , address or coordinates. Useful for designers of GSHP systems.
An example is the GeoReport from BGS. This is modular in nature and tailored to the users requirements (see http://shop.bgs.ac.uk/GeoReports)

Unit	Age	Thermal conductivity W m^{-1} K^{-1}	Thermal diffusivity m^2 day^{-1}	Thickness Metres
Bedrock (below rockhead)				
Alluvium	Holocene	1.67	0.056	2-5
River Terrace deposits	Quaternary	2.50	0.079	6-7
London Clay Formation	Palaeogene	1.79	0.0849	1-5
Harwich Formation	Palaeogene	2.4	0.1206	2
Lambeth Group	Palaeogene	2.2	0.1078	10-15
Thanet Sand	Palaeogene	2.35	0.1074	25-30
Chalk Group	Late Cretaceous	1.67	0.0745	200+

The values quoted for the Alluvium and River Terrace deposits assume saturated conditions. In the event that the deposits dried out lower values for both thermal conductivity and thermal diffusivity would be more appropriate. Average thermal properties for a 100 m borehole are a thermal conductivity of 1.94 W m^{-1} K^{-1} and a thermal diffusivity of 0.0886 m^2 day^{-1}.

GSHP industry requirements


British Geological Survey
GeoReports

BGS Wallingford
Maclean Building
Crow marsh Gifford
Wallingford
OX10 8BB

Horizontal Loop Ground Source Heat Pump Report

This report is for closed loop near surface systems and contains a geological map with descriptions of rock types, estimates of mean annual ground temperatures and thermal properties.

Ground source heat pumps (GSHP) can provide low carbon solutions for space heating and cooling of residential and commercial buildings. GSHP systems have relatively low running costs but relatively high installation costs. Much of the cost is associated with installation of the external loop and is strongly affected by the geological and environmental conditions at the site. The site factors can affect both the heating and cooling performance of the heat pump and the drilling-trenching methods and costs.

Includes:
Location and extent of site
Predicted thermal conductivity at a depth of 1.5 m
Temperatures

Extra information available at an additional cost:
Geological map extracts
Thickness of superficial deposits

Report Id: GR_999999/2

Client reference:

Can we provide

- Horizontal loop and vertical borehole reports (not modular)
- Delivered on-line by return
- Perhaps administered via a logon through the GSHPA website?
- At a cheaper price

...............but a vertical geological section requires manual input

We need to work more closely together

- Our data needs ground truthing
- Could we gain access to thermal response tests on a quid pro quo basis
- We need a national register of where GSHPs are installed

Conclusions

- Thermal conductivity is a key parameter when designing closed loop ground collectors
- UK based tables of thermal conductivity are better than ones based on continental or overseas values, but they are still generalised
- Between us we have a valuable resource
  - 4727 lab based measurements
  - An ever increasing database of thermal response tests

We need to work more closely together