Hot Dry Rocks Pty Ltd
Geothermal Energy Consultants

HEAD OFFICE
PO Box 251
South Yarra, Vic 3141
Australia
T +61 3 9867 4078
F +61 3 9279 3955
E info@hotdryrocks.com
W www.hotdryrocks.com

ABN: 12 114 617 622

SERVICES
Exploration
Rock Property Measurements
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Thermal conductivity of core samples KEN043 – KEN059

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Executive summary

KUTh commissioned Hot Dry Rocks Pty Ltd (HDRPL) to measure the thermal conductivity of 16 core specimens delivered in mid July, 2008. Measurements were made on the 16 specimens using a steady state divided bar apparatus calibrated for the range 1.4–9.8 W/mK. Up to four samples were prepared from each specimen to investigate variation in thermal conductivity over short distance scales and to determine mean conductivity and uncertainty. All values were measured at a standard temperature of 30°C. The uncertainty for individual samples is from ± 4.0% to ± 10%.

HDRPL considers the following points to be important:

- Results for some sequences fall in the range typical for good thermal insulators, while other sequences do not exhibit such thermal insulating abilities.
- While the specimens were chosen to represent the cored geological sections from which they came, there is no guarantee that the sections themselves are typical of the overall geological formations.
- It is to be expected that the thermal conductivity of a given formation will vary from place to place if the porosity of the formation varies.
- Thermal conductivity of rocks is sensitive to temperature. This should be kept in mind when developing models of in situ thermal conductivity.

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1.0 Introduction

Thermal conductivity is the physical property that controls the rate at which heat energy flows through a material in a given thermal gradient. In the S.I. system of units, it is measured in watts per metre-kelvin (W/mK). In the Earth, thermal conductivity controls the rate at which temperature increases with depth for a given heat flow. The thermal conductivity distribution within a section of crust must be known in order to calculate crustal heat flow from temperature gradient data, or to predict temperature distribution from a given heat flow. This report describes the results of laboratory thermal conductivity measurements on a series of drill core samples from KUTh Energy Ltd.

KUTh commissioned Hot Dry Rocks Pty Ltd (HDRPL) to undertake this study. HDRPL took delivery of 16 core specimens[1] from the wells Kingston, Woodsdale, Tiberias, and Fingal in mid July 2008 (Table 1). Thermal conductivity measurements were made on all of these specimens using a steady state divided bar apparatus calibrated for the range 1.4–9.8 W/mK.

Thermal conductivity is sensitive to temperature, in general decreasing as temperature increases. The measurements contained in this report were made within ±2°C of 30°C.

[1] In this report the word "specimen" refers to a raw piece of rock delivered to HDRPL, while "sample" refers to part of a specimen prepared for conductivity measurement. In general, three samples are prepared from each specimen.

Table 1. Specimens presented for thermal conductivity measurement.

Specimen	Well Name	Depth From	Depth To
KEN043	Kingston	99.1 m	99.1 m
KEN044	Kingston	129.2 m	129.3 m
KEN045	Kingston	200.97 m	201.09 m
KEN046	Woodsdale	123.33 m	123.43 m
KEN047	Woodsdale	211.65 m	211.74 m
KEN048	Woodsdale	105.77 m	105.94 m
KEN049	Woodsdale	154.54 m	154.64 m
KEN050	Tiberias	166.69 m	166.79 m
KEN051	Tiberias	195.94 m	196.07 m
KEN052	Tiberias	124.74 m	124.87 m
KEN053	Tiberias	211.59 m	211.69 m
KEN054	Fingal	87.1 m	87.2 m
KEN055	Fingal	233.1 m	233.21 m
KEN056	Fingal	183.7 m	183.83 m
KEN057	Fingal	204.78 m	204.9 m
KEN058	Fingal	144.77 m	144.85 m
KEN059	Fingal	52.75 m	52.86 m

2.0 Methodology

Hot Dry Rocks Pty Ltd received 16 specimens of rock from KUTh. HDRPL assumed that the specimens were representative of the average lithological composition of the formation being sampled.

Each specimen was prepared for thermal conductivity measurement in a divided bar apparatus[2]. Where possible, three prisms were cut from each consolidated core, each approximately 1/5 to 1/3 the diameter of the specimen in thickness. Three samples were taken to investigate variation in thermal conductivity over short distance scales and to determine mean conductivity and uncertainty. The samples were all of a circular/cylindrical shape. Each sample was ground flat and polished, then evacuated under >95% vacuum for a minimum of three hours. Samples were then submerged in water prior to returning to atmospheric pressure. Water saturation continued at atmospheric pressure for a minimum of three hours, and all samples were left in water until just prior to conductivity measurement. Due to excessive friability, KEN058 was tested for thermal conductivity while encased within a hollow cell.

Values were measured at a standard temperature of 30°C (±2°C). Harmonic mean conductivity (see Figure 1) and one standard deviation uncertainty were calculated for each specimen. Results are presented in the next section.

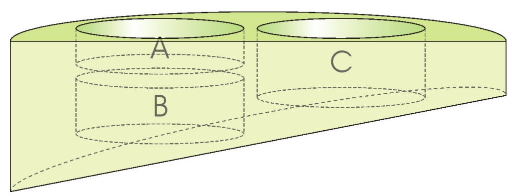

Figure 1. The average conductivity of samples in series (e.g. A and B) is found using the harmonic mean. The average conductivity of samples in parallel (e.g. A and C) is found using the arithmetic mean.

[2] Divided bar apparatus: An instrument that places an unknown sample in series with a standard of known thermal conductivity, then imposes a constant thermal gradient across the combination in order to derive the conductivity of the unknown sample.

3.0 Results

Table 2 displays the thermal conductivity for each individual sample, and the harmonic mean conductivity and standard deviation for each specimen. All values are for a standard temperature of 30°C. The uncertainty for individual samples is approximately ±4% – ±10% for consolidated samples (based on the instrument precision of the divided bar apparatus).

Table 2. Thermal conductivity of samples at 30°C, and harmonic mean and uncertainty[3] for each specimen.

Well	Fm/lith	Depth From	Depth To	Sample		Conductivity W/mK	
	Jurassic				A	1.92	
	Dolerite				B	1.92	
Kingston		99.1 m	99.2 m	KEN043	C	1.90	1.91 ± 0.01
	Jurassic				A	1.89	
	Dolerite				B	1.86	
Kingston		129.2 m	129.3 m	KEN044	C	1.90	1.88 ± 0.02
	Jurassic				A	1.98	
	Dolerite				B	1.96	
Kingston		200.97 m	201.09 m	KEN045	C	1.98	1.97 ± 0.01
	?Parmeener				A	2.47	
	Silty sst				B	2.74	
Woodsdale		123.33 m	123.43 m	KEN046	C	2.55	2.58 ± 0.14
	Jurassic				A	2.42	
	Dolerite				B	2.49	
Woodsdale		211.65 m	211.74 m	KEN047	C	2.55	2.49 ± 0.07
	?Parmeener				A	4.60	
	Sst lithic				B	4.49	
Woodsdale		105.77 m	105.94 m	KEN048	C	4.54	4.54 ± 0.06
	Jurassic				A	2.28	
	Dolerite				B	2.27	
Woodsdale		154.54 m	154.64 m	KEN049	C	2.29	2.28 ± 0.01
	?Parmeener				A	4.55	
	Sst				B	4.18	
Tiberias		166.69 m	166.79 m	KEN050	C	4.82	4.50 ± 0.32

[3] Uncertainty of the thermal conductivity for each specimen is one standard deviation of the measured values.

Well	Fm/lith	Depth From	Depth To	Sample		Conductivity W/mK	
Tiberias	?Parmeener Silt st.	195.94 m	196.07 m	KEN051	A	2.20	
					B	2.22	
					C	2.34	2.25 ± 0.08
Tiberias	?Parmeener Sst	124.74 m	124.87 m	KEN052	A	3.28	
					B	3.47	
					C	3.15	3.30 ± 0.16
Tiberias	?Parmeener Fine Silt st.	211.59 m	211.69 m	KEN053	A	1.95	
					B	1.61	
					C	1.59	1.70 ± 0.20
Fingal	?Parmeener Silt st.	87.1 m	87.2 m	KEN054	A	1.85	
					B	1.83	
					C	1.87	1.85 ± 0.02
Fingal	?Parmeener Silty sst	233.1 m	233.21 m	KEN055	A	2.20	
					B	2.21	
					C	2.18	2.20 ± 0.02
Fingal	?Parmeener Silty sst	183.7 m	183.83 m	KEN056	A	2.54	
					B	2.70	
					C	2.27	
					D	2.66	2.53 ± 0.19
Fingal	?Parmeener Carb mudst	204.78 m	204.9 m	KEN057	A	0.57	
					B	0.88	
					C	0.67	0.68 ± 0.16
Fingal	?Parmeener Carb mudst	144.77 m	144.85 m	KEN058	A	1.03	
					B	1.07	
					C	1.05	1.05 ± 0.02
Fingal	Jurassic Dolerite	52.75 m	52.86 m	KEN059	A	2.09	
					B	2.06	
					C	2.07	2.07 ± 0.01

4.0 Discussion and conclusions

In the case of all wells (Kingston, Woodsdale, Tiberias, and Fingal), the measured values agree closely for samples taken from the same specimen. This implies that variation in thermal conductivity is not significant over the scale of centimetres for the specimens examined. There does however appear to be a variation in thermal conductivity on the kilometre scale for the Woodsdale, Tiberias, and Fingal wells.

In the case of the Kingston well, given that there is only about 3% variation from the mean conductivity (about 1.9 W/mK) across specimens, variation on the kilometre scale through that sequence also appears low.

For the Woodsdale well, there is 24% variation from the mean conductivity (about 3.0 W/mK) across specimens; for the Tiberias well, there is about 41% variation from the mean conductivity (about 3.0 W/mK) across specimens; For the Fingal well, there is about 60% variation from the mean conductivity (about 1.7 W/mK) across specimens. Variation on the kilometre scale through sequences in these wells appears significant and should be considered.

The conductivities recorded from these specimens vary from the low to high range for geologic sequences. The results suggest that while some of the formations assessed in this study could act as attractive thermal insulation for geothermal systems, others may not.

The following additional points must be considered if extrapolating the results in this report to in situ formations:

1. The samples upon which the thermal conductivity measurements were made are only several square centimetres in surface area. While the specimens were chosen to represent the geological sections from which they came, there is no guarantee that the sections themselves are typical of the overall geological formations. This is especially true for heterogeneous formations. This introduces an unquantifiable random error into the results.

2. Porosity exerts a primary influence on the thermal conductivity of a rock. Water is substantially less conductive than typical mineral grains[4], and water saturated pores act to reduce the bulk thermal conductivity of the rock. Gas-filled pores reduce the bulk conductivity even more dramatically. Results reported in this document are whole-rock measurements. No adjustments were made for porosity. It is to be expected that the thermal conductivity of a given formation will vary from place to place if the porosity of the formation varies (conductivity decreases with increasing porosity).

3. Thermal conductivity of rocks is sensitive to temperature. This should be kept in mind when developing models of *in situ* thermal conductivity.

[4] **Beardsmore, G.R. and Cull, J.P.** (2001). *Crustal heat flow: A guide to measurement and modelling*. Cambridge University Press, Cambridge. 324pp.