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SERVICES
Exploration
Rock Property Measurements
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Thermal conductivity of core samples KEN101-KEN110

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Executive summary

KUTh Energy commissioned Hot Dry Rocks Pty Ltd (HDRPL) to measure the thermal conductivity of 10 core specimens delivered in mid December 2009. Measurements were made on the 10 specimens using a steady state divided bar apparatus calibrated for the range 1.4–9.8 W/mK. Up to three 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 25°C. The uncertainty for individual samples is ± 3.5%.

HDRPL considers the following points to be important:

- 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.

KUTh Energy commissioned Hot Dry Rocks Pty Ltd (HDRPL) to undertake this study. HDRPL took delivery of 10 core specimens[1] from the wells Bangor, Bluestone, and Swan in December 2009 (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 25°C.

Table 1. Specimens presented for thermal conductivity measurement.

Sample	Well	Depth From	Depth To
KEN101	Bangor	116.37 m	116.68 m
KEN102	Bangor	163.08 m	163.23 m
KEN103	Bangor	206.5 m	206.67 m
KEN104	Bangor	225.86 m	226.06 m
KEN105	Bluestone	114.80 m	115.00 m
KEN106	Bluestone	175.20 m	175.52 m
KEN107	Bluestone	203.24 m	203.45 m
KEN108	Swan	161.49 m	161.71 m
KEN109	Swan	129.05 m	219.26 m
KEN110	Swan	279.22 m	279.41 m

[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.

2.0 Methodology

Hot Dry Rocks Pty Ltd received 10 specimens of rock from KUTh Energy. 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 1/4 to 1/3 the diameter of the specimen in thickness. These 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.

Values were measured at a standard temperature of 25°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.

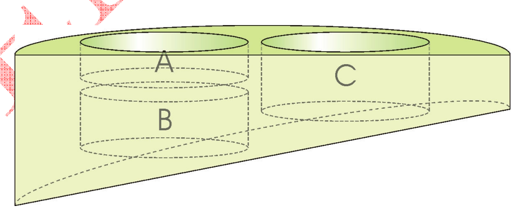

Figure 1. The average conductivity of samples in series (e.g. A and B) is found using the harmonic mean. The average conductivity of samples in parallel (e.g. A and C) is found using the arithmetic mean.

[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 25°C. The uncertainty for individual samples is approximately ±3.5% for consolidated samples (based on the instrument precision of the divided bar apparatus).

Table 2. Thermal conductivity of samples at 25°C, and harmonic mean and uncertainty[3] for each specimen.

Well	Lith/Fm	Depth From	Depth To	Sample		Conductivity (W/mK)	
	Black shale				A	3.30	
	Mathinna ?				B	3.38	
Bangor		116.37 m	116.68 m	KEN101	C	3.43	3.37 ± 0.06
	Black shale				A	3.29	
	Mathinna ?				B	2.80	
Bangor		163.08 m	163.23 m	KEN102	C	2.56	2.85 ± 0.37
	Black shale				A	1.76	
	Mathinna ?				B	2.23	
Bangor		206.5 m	206.67 m	KEN103	C	2.25	2.06 ± 0.28
	Siliceous shale				A	3.81	
Bangor	Mathinna ?	225.86 m	226.06 m	KEN104	B	3.73	3.77 ± 0.05
	Dolerite				A	2.03	
	Jurassic				B	2.12	
Bluestone		114.80 m	115.00 m	KEN105	C	2.07	2.07 ± 0.05
	Dolerite				A	2.19	
	Jurassic				B	2.17	
Bluestone		175.20 m	175.52 m	KEN106	C	2.18	2.18 ± 0.01
	Dolerite				A	2.21	
	Jurassic				B	2.22	
Bluestone		203.24 m	203.45 m	KEN107	C	2.17	2.20 ± 0.03
	Dolerite				A	2.07	
	Jurassic				B	1.93	
Swan		161.49 m	161.71 m	KEN108	C	1.95	1.98 ± 0.07

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

Swan	Dolerite Jurassic	129.05 m	129.26 m	KEN109	A B C	2.10 2.14 2.09	2.11 ± 0.03
Swan	Dolerite Jurassic	179.22 m	179.41 m	KEN110	A B C	2.15 2.08 2.16	2.13 ± 0.05

4.0 Discussion and conclusions

In most cases (excluding KEN102 and KEN103), significant variation in thermal conductivity is not observed within the samples taken from a specimen. This implies that variation in thermal conductivity appears low over the scale of centimetres for those specimens.

Some variation is however observed within the samples from the siltstone specimens KEN102 and KEN103, likely due to variation in their grain-size and mineralogy. This implies that variation in thermal conductivity may be significant over the scale of centimetres for those specimens. Additionally, given that there is approximately 30% from the mean conductivity (approximately 3.0 W/mK for the well Bangor) across specimens, variation on the kilometre scale through that sequence also appears significant.

For the wells Bluestone and Swan, given that there is only about 10% variation from the mean conductivity (2.15 W/mK for the well Bluestone, and 2.07 W/mK) across specimens, variation on the kilometre scale through those sequences appears low.

The conductivities recorded from these specimens are in the low to normal range for sedimentary sequences. The results suggest that the formations assessed in this study could act as attractive thermal insulation for geothermal systems.

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.