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SERVICES
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Thermal conductivity of core samples KEN080-KEN100

Prepared for KUTh Energy

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Executive summary

KUTh Energy commissioned Hot Dry Rocks Pty Ltd (HDRPL) to measure the thermal conductivity of 21 core specimens delivered in late September 2008. Measurements were made on the 21 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%.

HDRPL considers the following points to be important:

- The dolerite specimens show thermal conductivities typical for its lithology, ranging from approximately 2.0 W/mK to 2.5 W/mK. The well Frankford shows a contrast in thermal conductivity between its two key lithologies, dolerite and sand/siltstone, with latter (KEN087, KEN088) showing higher thermal conductivity values of 3.0 W/mK to 3.26 W/mK. The siltstones from the well Nunmarra (KEN091, and KEN092) show thermal conductivity values of 2.17 W/mK to 2.23 W/mK.
- 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 KEN.

KUTh Energy (KEN) commissioned Hot Dry Rocks Pty Ltd (HDRPL) to undertake this study. HDRPL took delivery of 21 core specimens[1] from the wells Charlton, Frankford, Nunmarra, Perth, and Westbury in September 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 25°C.

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[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.

Sample	Well	Depth From	Depth To
KEN080	Charlton	30.86 m	31.00 m
KEN081	Charlton	81.56 m	81.73 m
KEN082	Charlton	122.77 m	188.90 m
KEN083	Charlton	188.77 m	188.90 m
KEN084	Charlton	228.67 m	228.67 m
KEN085	Frankford	116.85 m	117.05 m
KEN086	Frankford	186.03 m	186.23 m
KEN087	Frankford	208.81 m	208.94 m
KEN088	Frankford	245.04 m	245.22 m
KEN089	Nunamara	74.00 m	74.14 m
KEN090	Nunamara	144.00 m	144.16 m
KEN091	Nunamara	224.23 m	224.40 m
KEN092	Nunamara	244.20 m	244.34 m
KEN093	Perth	129.99 m	130.15 m
KEN094	Perth	158.11 m	158.28 m
KEN095	Perth	177.09 m	177.22 m
KEN096	Perth	228.00 m	228.15 m
KEN097	Westbury	110.30 m	110.45 m
KEN098	Westbury	158.17 m	158.34 m
KEN099	Westbury	179.21 m	179.35 m
KEN100	Westbury	223.96 m	224.13 m

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2.0 Methodology

Hot Dry Rocks Pty Ltd received 21 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 1/3 to 1/2 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.

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.

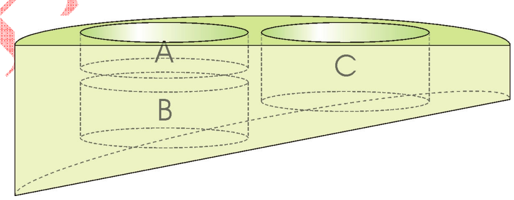

Figure 1. The average conductivity of samples in series (e.g. A and B) is found using the harmonic mean. The average conductivity of samples in parallel (e.g. A and C) is found using the arithmetic mean.

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[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% 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	Fm/lith	Depth From	Depth To	Sample		Conductivity (W/mK)			
	Jurassic				A	2.33			
					B	2.23			
Charlton	dolerite	30.86 m	31.00 m	KEN0 80	C	2.23	2.26	±	0.06
	Jurassic				A	2.22			
					B	2.33			
Charlton	dolerite	81.56 m	81.73 m	KEN0 81	C	2.21	2.25	±	0.06
	Jurassic				A	2.18			
					B	2.36			
Charlton	dolerite	122.77 m	188.90 m	KEN0 82	C	2.31	2.28	±	0.09
	Jurassic				A	2.34			
					B	2.16			
Charlton	dolerite	188.77 m	188.90 m	KEN0 83	C	2.2	2.23	±	0.1
	Jurassic				A	2.13			
					B	2.32			
Charlton	dolerite	228.67 m	228.67 m	KEN0 84	C	2.31	2.25	±	0.11
	Jurassic				A	2.43			
					B	2.4			
Frankford	dolerite	116.85 m	117.05 m	KEN0 85	C	2.24	2.35	±	0.1
	Jurassic				A	2.17			
					B	2.19			
Frankford	dolerite	186.03 m	186.23 m	KEN0 86	C	2.15	2.17	±	0.02

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

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Frankford	? Silty Sst	208.81 m	208.94 m	KEN0 87	A B C	2.68 3.01 3.41	3	±	0.37
Frankford	? Sst	245.04 m	245.22 m	KEN0 88	A B C	3.2 3.25 3.34	3.26	±	0.07
Nunamara	Jurassic dolerite	74.00 m	74.14 m	KEN0 89	A B C	2.45 2.55 2.43	2.47	±	0.06
Nunamara	Jurassic dolerite	144.00 m	144.16 m	KEN0 90	A B C	2.21 2.26 2.31	2.26	±	0.05
Nunamara	? alt. silt st	224.23 m	224.40 m	KEN0 91	A B C	2.12 2.18 2.22	2.17	±	0.05
Nunamara	? alt. silt st	244.20 m	244.34 m	KEN0 92	A B C	2.22 2.22 2.25	2.23	±	0.01
Perth	Jurassic dolerite	129.99 m	130.15 m	KEN0 93	A B C	2.17 2.18 2.14	2.16	±	0.02
Perth	Jurassic dolerite	158.11 m	158.28 m	KEN0 94	A B C	2.33 2.23 2.53	2.36	±	0.15
Perth	Jurassic dolerite	177.09 m	177.22 m	KEN0 95	A B C	2.45 2.4 2.38	2.41	±	0.03
Perth	Jurassic dolerite	228.00 m	228.15 m	KEN0 96	A B C	2.07 2.02 2.12	2.07	±	0.05
Westbury	Jurassic dolerite	110.30 m	110.45 m	KEN0 97	A B C	2.04 2.17 2.21	2.14		0.09

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Westbury	Jurassic dolerite	158.17 m	158.34 m	KEN098	A	2.07	2.07	±	0.03
					B	2.11			
					C	2.05			
Westbury	Jurassic dolerite	179.21 m	179.35 m	KEN099	A	2.3	2.15	±	0.13
					B	2.05			
					C	2.12			
Westbury	Jurassic dolerite	223.96 m	224.13 m	KEN100	A	2.14	2.21	±	0.07
					B	2.2			
					C	2.28			

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4.0 Discussion and conclusions

In most cases, 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. KEN087 is exceptional and shows a higher standard deviation between it three individual samples KEN087A, KEN087B, and KEN087C, indicating that variation in thermal conductivity over the scale of centimetres may be significant. It should be noted that KEN087 additionally shows interbedding of sand and silt layers, presumably the cause of the observed variation of thermal conductivity between samples.

Given that there is less than about 10% variation from the mean conductivity across specimens from the wells Charlton, Nunmarra, Perth, and Westbury, variation on the kilometre scale within each well appears low. Thermal conductivity values for the samples measured from the well Frankford, however, show a significant 20% variation from the mean conductivity of that well.

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

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

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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.

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