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SERVICES
Exploration
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Thermal conductivity of core samples KEN060-KEN076, KEN078-KEN079

Prepared for KUTh Energy Ltd (KEN)

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Executive summary

KUTh Energy Ltd (KEN) commissioned Hot Dry Rocks Pty Ltd (HDRPL) to measure the thermal conductivity of 20 core specimens delivered in mid August 2008. Measurements were made on the 19 of the 20 specimens using a steady state divided bar apparatus calibrated for the range 1.4–9.8 W/mK. 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 30°C. The uncertainty for individual samples is ± 3.5%.

HDRPL considers the following points to be important:

- Results for wells Mt Nicholas and Macquarie show significant variability with depth.
- 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.

KEN commissioned HDRPL to undertake this study. HDRPL obtained 20 core specimens[1] from the wells Bangor, Mt Nicholas, Le Mont, Tunbridge, and Macquarie in August 2008 (Table 1). Thermal conductivity measurements were made on 19 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	Depth From	Depth To
KEN060	Bangor	145.43 m	145.59 m
KEN061	Mt Nicholas	30.4 m	30.5 m
KEN062	Mt Nicholas	63.9 m	64.05 m
KEN063	Mt Nicholas	82.17 m	82.27 m
KEN064	Mt Nicholas	200.57 m	200.7 m
KEN065	Mt Nicholas	107.85 m	107.95 m
KEN066	Mt Nicholas	144.8 m	144.92 m
KEN067	Mt Nicholas	211.55 m	211.68 m
KEN068	Le Mont	115.02 m	115.13 m
KEN069	Le Mont	161.8 m	161.9 m
KEN070	Le Mont	208.56 m	208.67 m
KEN071	Le Mont	225.35 m	225.45 m
KEN072	Turnbridge	120.00 m	120.19 m
KEN073	Turnbridge	159.66 m	159.77 m
KEN074	Turnbridge	218.20 m	218.30 m
KEN075	Turnbridge	238.1 m	238.22 m
KEN076	Macquarie	110.40 m	110.55 m
KEN077	Macquarie	151.5 m	151.62 m
KEN078	Macquerie	174.8 m	174.90 m
KEN079	Macquarie	204.0 m	204.12 m

2.0 Methodology

Hot Dry Rocks Pty Ltd selected samples of rock from each of the 20 cores, based on them being visually representative of the average lithological composition of the formation being sampled. The specimens were labelled, bagged and shipped to HDRPL's laboratory in South Yarra.

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 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.

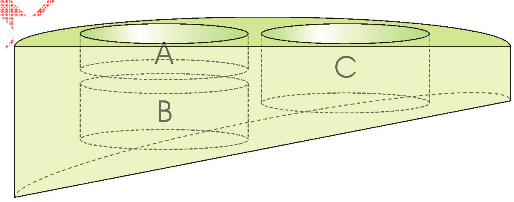

Figure 1. The average conductivity of samples in series (e.g. A and B) is found using the harmonic mean. The average conductivity of samples in parallel (e.g. A and C) is found using the arithmetic mean.

[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 ±3.5% 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	Depth From	Depth To	Sample			Conductivity (W/mK)
				A	3.31	
				B	3.40	
Bangor	145.43 m	145.59 m	KEN060	C	3.38	3.36 ± 0.05
				A	2.09	
				B	2.14	
Mt Nicholas	30.4 m	30.5 m	KEN061	C	2.11	2.11 ± 0.03
				A	1.91	
				B	1.69	
Mt Nicholas	63.9 m	64.05 m	KEN062	C	1.96	1.85 ± 0.14
				A	2.50	
				B	2.58	
Mt Nicholas	82.17 m	82.27 m	KEN063	C	2.69	2.59 ± 0.10
				A	4.82	
				B	4.73	
Mt Nicholas	200.57 m	200.7 m	KEN064	C	4.86	4.80 ± 0.07
				A	2.95	
				B	2.80	
Mt Nicholas	107.85 m	107.95 m	KEN065	C	2.82	2.85 ± 0.08
				A	4.01	
				B	4.24	
Mt Nicholas	144.8 m	144.92 m	KEN066	C	4.29	4.18 ± 0.15
				A	4.79	
				B	4.72	
Mt Nicholas	211.55 m	211.68 m	KEN067	C	4.64	4.72 ± 0.08

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

				A	2.28	
				B	2.10	
Le Mont	115.02 m	115.13 m	KEN068	C	2.09	2.15 ± 0.11
				A	2.16	
				B	2.06	
Le Mont	161.8 m	161.9 m	KEN069	C	2.06	2.09 ± 0.06
				A	2.33	
				B	2.28	
Le Mont	208.56 m	208.67 m	KEN070	C	2.31	2.31 ± 0.02
				A	2.23	
				B	2.34	
Le Mont	225.35 m	225.45 m	KEN071	C	2.34	2.30 ± 0.06
				A	2.16	
				B	2.09	
Turnbridge	120.00 m	120.19 m	KEN072	C	2.16	2.14 ± 0.04
				A	2.40	
				B	2.35	
Turnbridge	159.66 m	159.77 m	KEN073	C	2.40	2.39 ± 0.03
				A	1.94	
				B	2.04	
Turnbridge	218.20 m	218.30 m	KEN074	C	2.02	2.00 ± 0.06
				A	1.70	
				B	1.86	
Turnbridge	238.1 m	238.22 m	KEN075	C	1.95	1.83 ± 0.13
				A	4.95	
				B	4.95	
Macquarie	110.40 m	110.55 m	KEN076	C	4.99	4.96 ± 0.02
Macquarie	151.5 m	151.62 m	KEN077	Specimen is not testable		
				A	2.73	
				B	2.72	
Macquerie	174.8 m	174.90 m	KEN078	C	2.70	2.72 ± 0.01
				A	2.55	
				B	2.34	
Macquarie	204.0 m	204.12 m	KEN079	C	2.43	2.44 ± 0.11

4.0 Discussion and conclusions

In all 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. In the cases of the specimens taken from the wells Le Mont there appears to be low variability of thermal conductivity on the kilometre scale, with a variation from the mean conductivity of 6%. Specimens taken from the Tunbridge well had a variation of 14% from the mean conductivity.

In the cases of the specimens taken from the wells Mt Nicholas and Macquarie, however, variability appears to be significant on the kilometre scale, with a variation from the mean conductivity of 45% and 47% respectively.

The conductivities recorded from these specimens are in the low to high range and the results suggest that the formations assessed in this study could have sections that may 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

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

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.