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SERVICES
Exploration
Rock Property Measurements
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Thermal conductivity of core samples KEN146-KEN166

Prepared for KUTh Energy Ltd

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Executive summary

KUTh Energy Ltd (KEN) commissioned Hot Dry Rocks Pty Ltd (HDRPL) to measure the thermal conductivity of 21 core specimens delivered in April 2009. Measurements were made on each of the 21specimens 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 thermal conductivity of individual samples from 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 (KEN).

KEN commissioned Hot Dry Rocks Pty Ltd (HDRPL) to undertake this study. HDRPL took delivery of 21 core specimens[1] in April 2009 from the wells Beaconsfield 1, Lisle 1, Oatlands 2, Rocherlea 1, and Weymouth 1 (Table 1). Thermal conductivity and density measurements were made on all 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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Table 1. Specimens presented for thermal conductivity measurement.

[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.

Well	Formation	Depth From (m)	Depth To (m)	HDRPLSample ID
Beaconsfield 1	Jurassic Dolerite	126.01	126.13	KEN146
Beaconsfield 1	Jurassic Dolerite	177.13	177.29	KEN147
Beaconsfield 1	Jurassic Dolerite	223.26	223.40	KEN148
Beaconsfield 1	Parmeneer Sandstone	248.60	248.74	KEN149
Lisle 1	Mathinna Fm	115.06	115.23	KEN150
Lisle 1	Mathinna Fm	143.40	153.54	KEN151
Lisle 1	Mathinna Fm	151.48	151.62	KEN152
Lisle 1	Mathinna Fm	207.44	207.55	KEN153
Lisle 1	Mathinna Fm	240.48	240.59	KEN154
Oatlands 2	Jurassic Dolerite	115.60	115.70	KEN155
Oatlands 2	Jurassic Dolerite	136.51	136.66	KEN156
Oatlands 2	Jurassic Dolerite	191.10	191.21	KEN157
Oatlands 2	Jurassic Dolerite	226.90	227.06	KEN158
Rocherlea 1	Jurassic Dolerite	130.04	130.17	KEN159
Rocherlea 1	Jurassic Dolerite	181.03	181.12	KEN160
Rocherlea 1	Jurassic Dolerite	232.40	232.50	KEN161
Weymouth 1	Mathinna Fm	120.51	120.64	KEN162
Weymouth 1	Mathinna Fm	155.16	155.32	KEN163
Weymouth 1	Mathinna Fm	178.92	179.11	KEN164
Weymouth 1	Mathinna Fm	195.10	195.23	KEN165
Weymouth 1	Mathinna Fm	222.51	222.68	KEN166

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2.0 Methodology

HDRPL received 21 specimens of consolidated core from KUTh Energy Ltd. 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 ⅓ 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 generally all of a circular 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.

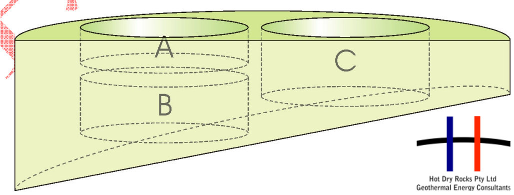

Figure 1. The average conductivity of samples in series (e.g. A and B) is found using the harmonic mean. The average conductivity of samples in parallel (e.g. A and C) is found using the arithmetic mean.

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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 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.

Formation	Lithology	Depth From (m)	Depth To (m)	Sample			Conductivity (W/mK)		
Jurassic Dolerite	Dolerite	126.01	126.13	KEN146	A	2.30	2.28	±	0.01
					B	2.27			
					C	2.28			
Jurassic Dolerite	Dolerite	177.13	177.29	KEN147	A	2.32	2.34	±	0.02
					B	2.35			
					C	2.36			
Jurassic Dolerite	Dolerite	223.26	223.40	KEN148	A	2.31	2.32	±	0.01
					B	2.34			
					C	2.31			
Parmeneer Sandstone	Sandstone	248.60	248.74	KEN149	A	2.90	2.82	±	0.11
					B	2.87			
					C	2.69			
Mathinna Fm	Siltstone	115.06	115.23	KEN150	A	4.33	4.18	±	0.17
					B	4.00			
					C	4.22			
Mathinna Fm	Meta-sandstone	143.40	153.54	KEN151	A	4.13	4.16	±	0.04
					B	4.20			
					C	4.16			
Mathinna Fm	Fine grained meta-sandstone, veined	151.48	151.62	KEN152	A	4.85	4.80	±	0.09
					B	4.87			
					C	4.70			
Mathinna Fm	Banded Silt-stone	207.44	207.55	KEN153	A	3.19	3.18	±	0.03
					B	3.20			
					C	3.14			

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

Mathinna Fm	Banded Silt-stone	240.48	240.59	KEN154	A	3.56	3.53	±	0.03
					B	3.50			
					C	3.54			
Jurassic Dolerite	Dolerite	115.60	115.70	KEN155	A	1.93	1.93	±	0.00
					B	1.93			
Jurassic Dolerite	Dolerite	136.51	136.66	KEN156	A	1.95	1.96	±	0.01
					B	1.97			
					C	1.96			
Jurassic Dolerite	Dolerite	191.10	191.21	KEN157	A	2.06	2.10	±	0.11
					B	2.03			
					C	2.22			
Jurassic Dolerite	Dolerite	226.90	227.06	KEN158	A	2.08	2.07	±	0.01
					B	2.06			
					C	2.07			
Jurassic Dolerite	Dolerite	130.04	130.17	KEN159	A	1.98	1.97	±	0.01
					B	1.95			
					C	1.97			
Jurassic Dolerite	Dolerite	181.03	181.12	KEN160	A	2.20	2.19	±	0.04
					B	2.22			
					C	2.15			
Jurassic Dolerite	Dolerite	232.40	232.50	KEN161	A	2.18	2.25	±	0.07
					B	2.27			
					C	2.31			
Mathinna Fm	Carbonaceous mudstone with dessеminated pyrite	120.51	120.64	KEN162	A	2.85	2.95	±	0.09
					B	3.01			
					C	2.98			
Mathinna Fm	Siltstone	155.16	155.32	KEN163	A	3.69	3.61	±	0.08
					B	3.61			
					C	3.54			
Mathinna Fm	Carbonaceous mudstone with desseminated pyrite	178.92	179.11	KEN164	A	3.97	3.93	±	0.05
					B	3.94			
					C	3.87			
Mathinna Fm	Carbonaceous mudstone with desseminated pyrite	195.10	195.23	KEN165	A	3.23	3.16	±	0.07
					B	3.10			
					C	3.16			

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Mathinna Fm	Slate	222.51	222.68	KEN166	A	4.09	4.02	±	0.14
					B	4.11			
					C	3.86			

4.0 Discussion and conclusions

For all specimens, significant variation between individual samples from the associated parent specimen is not observed; less than 5% variation from the mean conductivity is shown for all cases. Sample KEN166C, showing conductivity that is approximately 4% from the mean (4.02 W/mK), has been retested and confirmed of its conductivity. Sample KEN152B, showing conductivity that is nearly 5% from the mean (4.18 W/mK), has been retested and confirmed of its conductivity.

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).

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

5.0 Further anisotropy study

Showing some degree of foliation and/or bedding, specimens KEN162, KEN164, and KEN166 appear to be likely candidates for showing anisotropy of thermal conductivity and are recommended for further study. A full anisotropy study of each specimen involves the preparation of three individual cubes that are independently measured for thermal conductivity in each axis, x,y,z.

During such testing, the angle between the foliation of the rock sample and the direction of heat flow in the divided bar apparatus would be referred to as Θ and is measured to within 5°, as shown on Figure 2. The maximum angle Θ that can exist is 90°, in which case heat flow is perpendicular to the rock foliation. The minimum angle Θ that can exist is 0°, in which case heat flow is parallel to the rock foliation. The testing of thermal conductivity is generally carried out so that measurements in each axis x,y,z, are made, and are orthogonal to the foliation/bedding plane, so that for each cube, there will be a two measurements where Θ is 0° (x and y axis), and a single measurement where Θ is 90° (z axis).

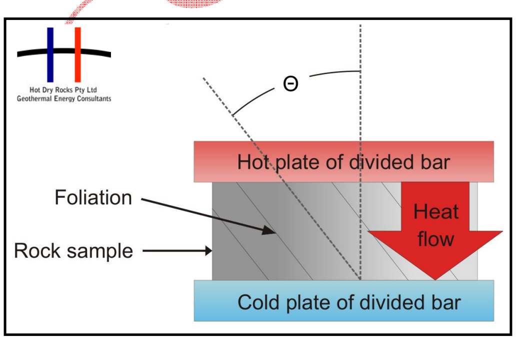

Figure 2. The value Θ referred to in this report is the angle (in degrees) between the heat flow and the rock sample's foliation.

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Ensuring that adequate specimen quantities exist is essential for a full anisotropy study to be successfully carried out.

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