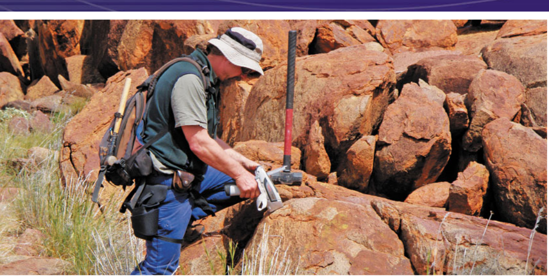
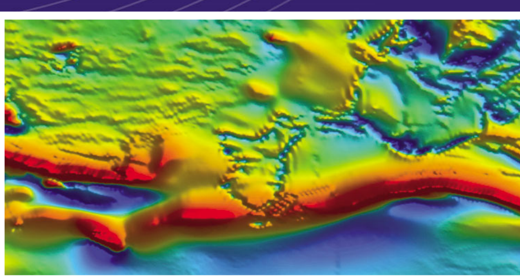
Government of **Western Australia**
Department of **Mines and Petroleum**

**RECORD 2010/23**

# GEOTHERMAL ENERGY POTENTIAL IN SELECTED AREAS OF WESTERN AUSTRALIA (BROWSE BASIN)

**by**
**Hot Dry Rocks Pty Ltd**


**Geological Survey of Western Australia**

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# GEOTHERMAL ENERGY POTENTIAL IN SELECTED AREAS OF WESTERN AUSTRALIA (BROWSE BASIN)

by
Hot Dry Rocks Pty Ltd[1]

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Perth 2010

Geological Survey of
Western Australia

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# Geothermal Energy Potential in Selected Areas of Western Australia (Browse Basin)

A report prepared for the Department of Mines and Petroleum, Western Australia

Report DMP0260909

July 2010

# Executive summary

Hot Dry Rocks Pty Ltd (HDR) was commissioned by the Department of Mines and Petroleum (DMP), Western Australia, to appraise the geothermal potential of four basins in Western Australia (the Browse, Bonaparte, Carnarvon and Officer basins) as part of Project DMP0260909.

A total of 74 wells were assessed; comprising 45 wells in the Carnarvon Basin, 17 wells in the Officer Basin, 10 wells in the Bonaparte Basin and two wells in the Browse Basin.

This report focuses on the Browse Basin. Two wells were assessed in detail for heat flow modelling.

The principle findings of this report are:-

- The Browse Basin lies entirely offshore and covers an area of approximately 185,000 km$^2$. The limited well penetrations and seismic data in the nearshore shallow water sections of the basin would suggest that current geothermal potential of the Browse Basin is limited.
- The Perth Core Library only holds limited core available for analysis from the Browse Basin. HDR was only able to collect four specimens for rock thermal conductivity measurements. The measured rock thermal conductivities for the specimens ranged between 2.29–4.51 W/mK.
- Heat flow was modelled for two wells. Formations intersected by those wells were not the same formations for which thermal conductivity data were measured. HDR therefore utilised conductivity data from similar lithologies in adjacent basins to assist in deriving values of apparent surface heat flow.
- Apparent surface heat flow values for the two modelled petroleum wells in the Browse Basin were 30 ± 3.3 mW/m$^2$ and 51 ± 6.8 mW/m$^2$. The uncertainties were derived from uncertainty in thermal conductivity. Additional uncertainty is inherent in the results because the temperature data used in the models were also poorly constrained.

**Authors**

Jim Driscoll compiled this report, aided by Ben Waining. Graeme Beardsmore reviewed the report and approved its release in its final form.

**Disclaimer**

The information and opinions in this report have been generated to the best ability of the author, and Hot Dry Rocks Pty Ltd (HDR) hope they may be of assistance to you. However, neither the author nor any other employee of HDR guarantees that the report is without flaw or is wholly appropriate for your particular purposes, and therefore we disclaim all liability for any error, loss or other consequence that may arise from you relying on any information in this publication. Base data utilised in this report were provided by the Department of Mines and Petroleum and HDR is not responsible for the quality or accuracy of these data.

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# 1. Introduction

The Department of Mines and Petroleum (DMP) provided Hot Dry Rocks Pty Ltd (HDR) with basic data packages for 74 wells in the Bonaparte, Browse, Carnarvon and Officer basins (Figure 1), including petroleum and stratigraphic well data, scanned log headers, bottom hole temperatures (BHTs), geological and geophysical reports, and other relevant data. HDR utilised these data and collected rock samples to provide new rock thermal conductivity data to use in the determination of apparent heat flow across the four basins as part of the overall assessment.

HDR was commissioned to utilise the supplied data to address the Scope of Services (Schedule 2; Section 1.2 of the *Request For Quote DMP0260909*) for the following topics:-

- determine depth of basement at the well locations
- verify geothermal data and extrapolate temperature to the basement
- generate isotherm maps at 100°C, 150°C and 200°C
- identify basement lithology from existing geophysical data
- relate basement lithology at depth from the existing data
- calculate the heat generating capacity of the basement rock

HDR was also requested to compile and comment on the adequacy of data on the current *in-situ* stress field in areas of potential Engineered Geothermal System (EGS) interest.

This report focuses on the two wells located within the Browse Basin (Attachment A). Given the limited well coverage, DMP advised that gridding of heat flow data and isothermal depth surfaces would not be required. Furthermore, a review of the EGS potential would also not be required. HDR was therefore only commissioned to supply a basic summary document for the geothermal potential of the Browse Basin.

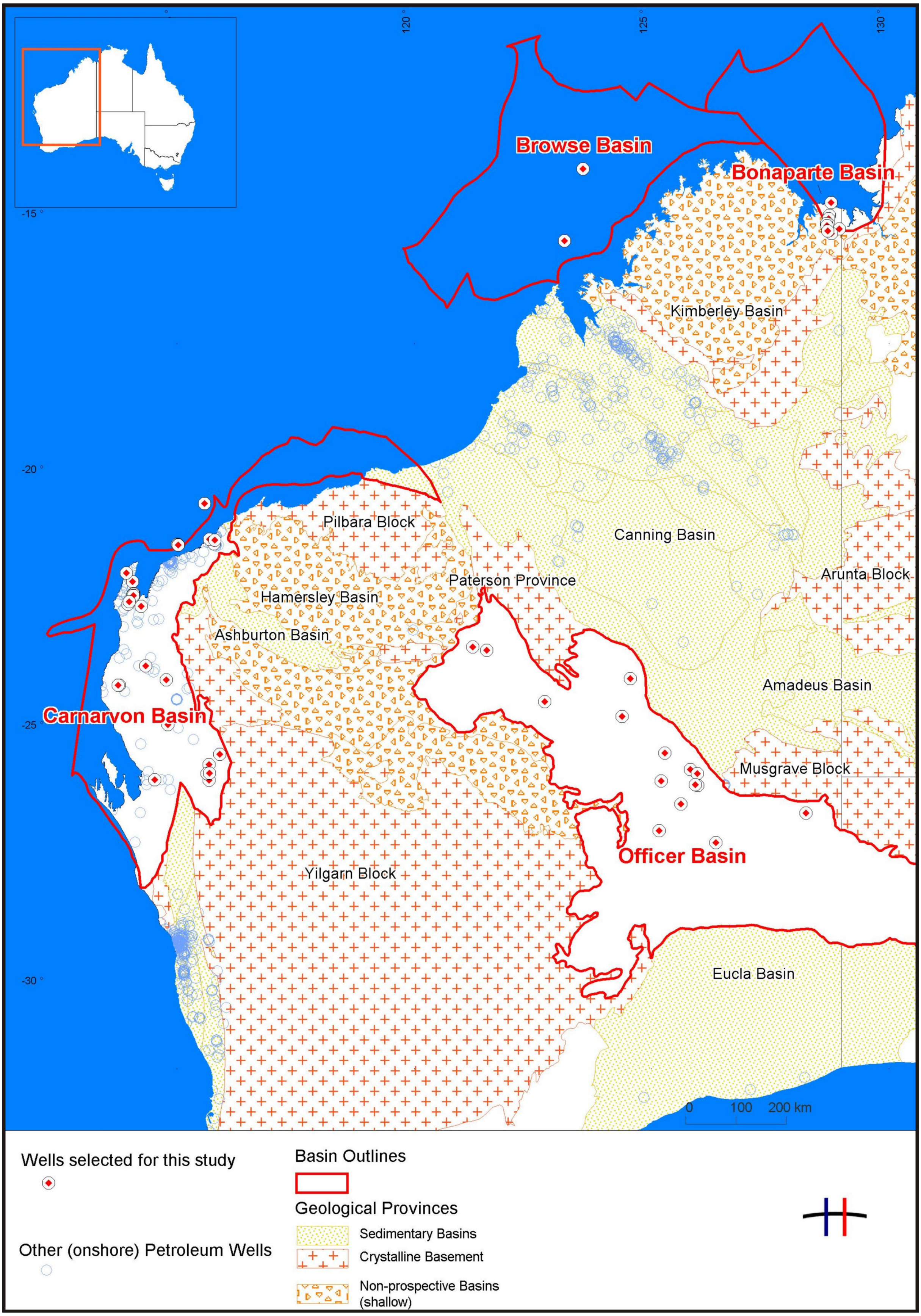


**Figure 1:** Location of the Bonaparte, Browse, Carnarvon and Officer basins, Western Australia (individual basin polygons modified from Geoscience Australia databases).

## 2. Browse Basin Geological Setting

The northeast-trending Browse Basin (Figure 2) is one of a string of sedimentary basins located off northwestern Australia's margin, collectively referred to as the Westralian Superbasin or North West Shelf, and covers a total area of approximately 185,000 km$^2$.

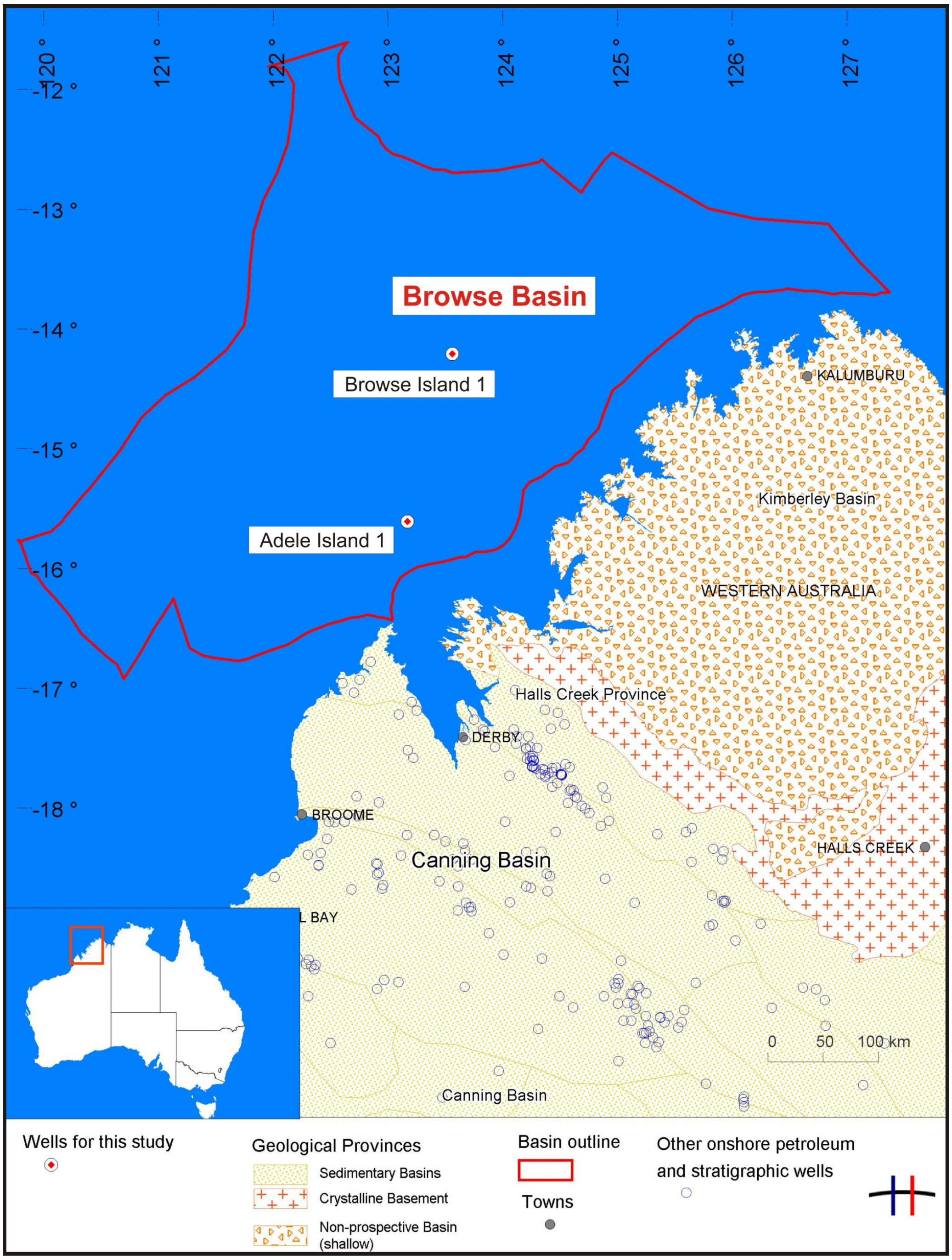


**Figure 2:** Location of the Browse Basin (basin polygon from Geoscience Australia database).

The Browse Basin is located offshore in water depths up to 2,000 m. The two wells that form this study are located on small coral atolls inboard of the main depocentres. The basin contains up to 12 km of sedimentary fill and was initiated as an intracratonic basin in the Late Carboniferous-Early Permian. The stratigraphy of the Browse Basin is summarised on Figures 3 and 4. A more detailed discussion of the structural evolution and stratigraphic succession can be found in Lavering and Pain (1991).

The basin is the focus of ongoing petroleum exploration activities. A number of large undeveloped gas/condensate fields have been identified in the outer and central areas, and small petroleum fields along the eastern margin.

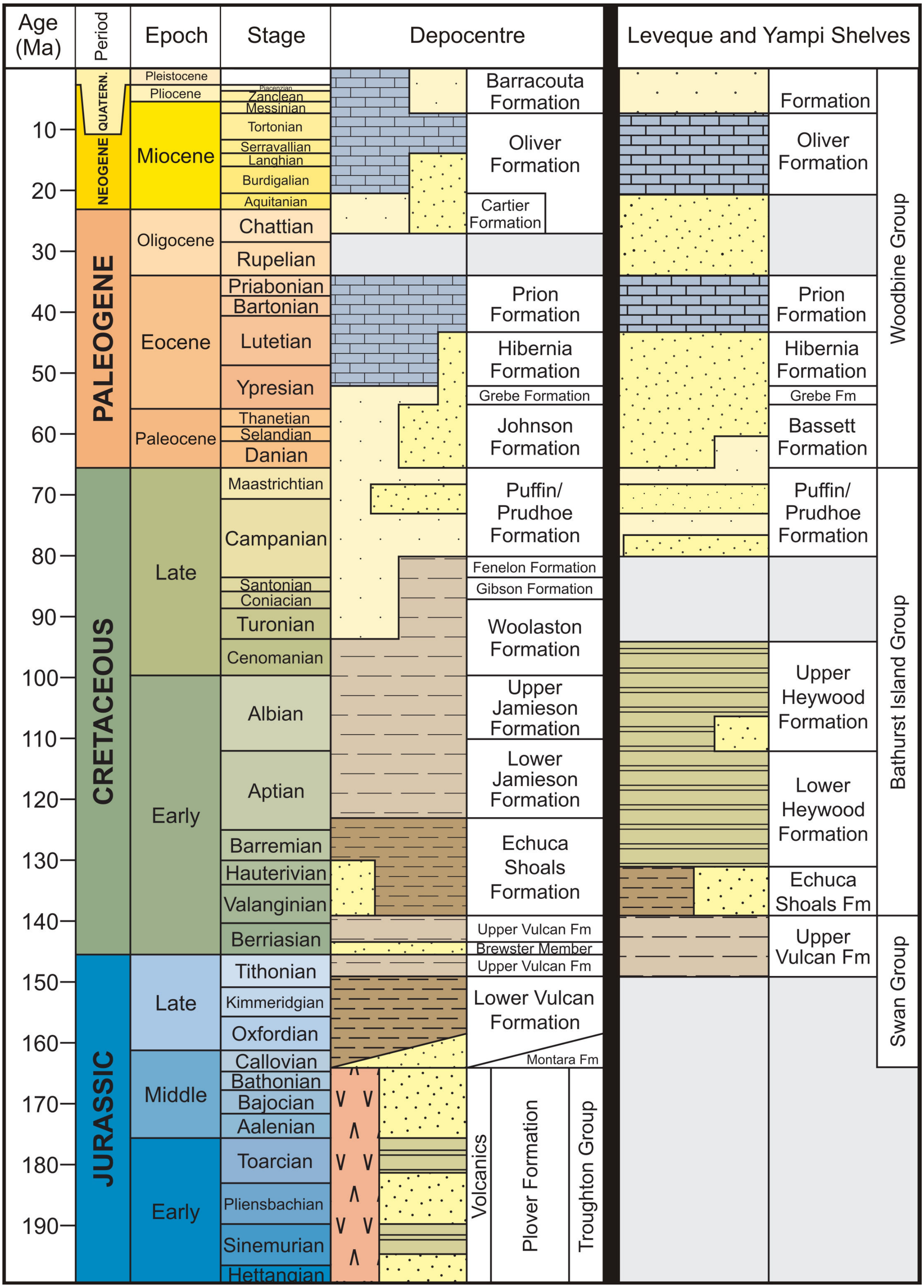


**Figure 3:** Stratigraphy of the Browse Basin Jurassic to Quaternary section (modified from file supplied by Ameed Ghori, DMP).

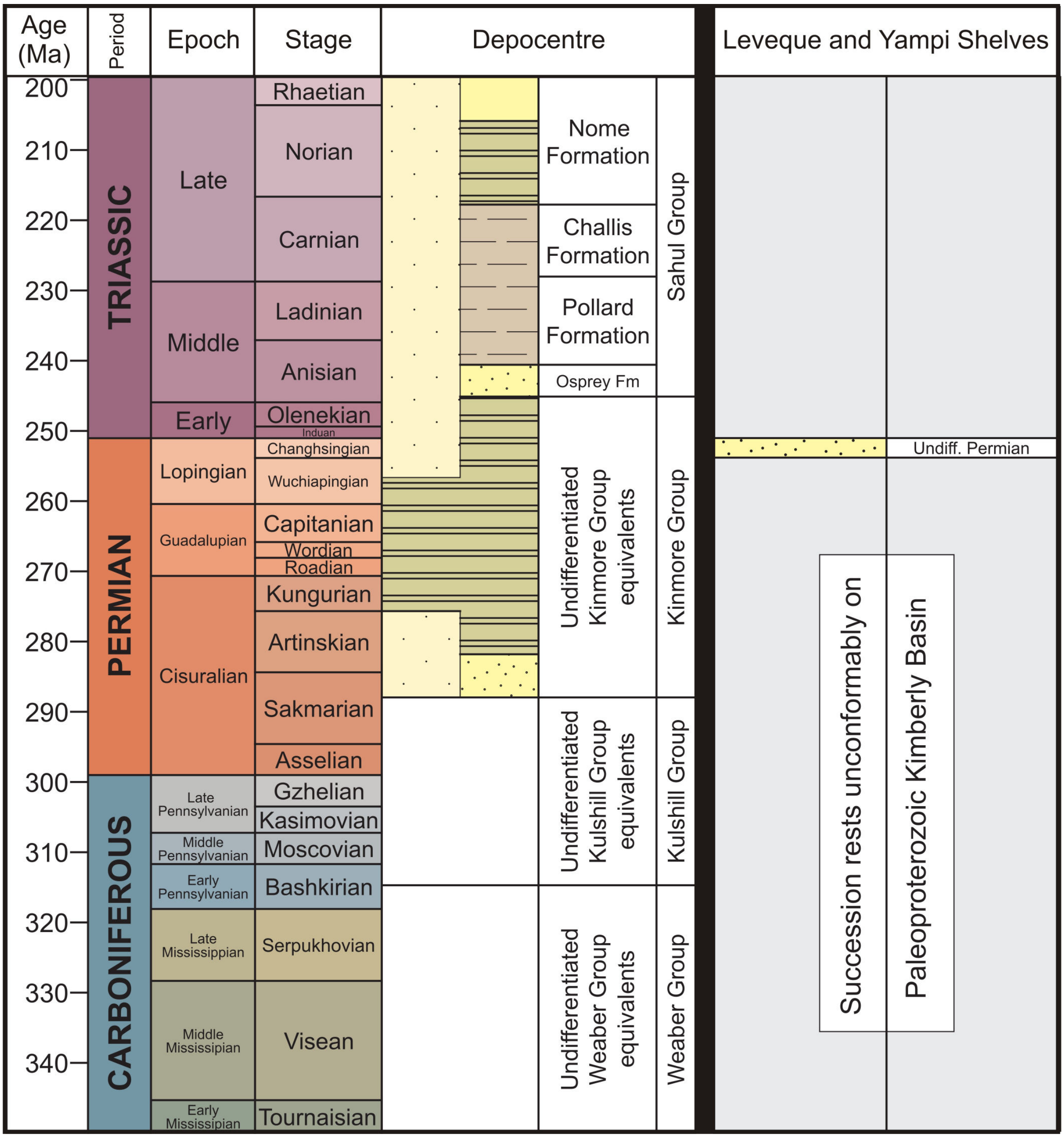


**Figure 4:** Stratigraphy of the Browse Basin Carboniferous to Triassic section (modified from file supplied by Ameed Ghori, DMP).

# 3. Basement Investigations

This section provides information for the following topics:-

For the two wells to be assessed:-

- determine depth of basement at the well locations
- identify basement lithology from existing geophysical data

### *3.1. Basement depth*

Adele Island-1 penetrated basement at 785 m. The OZ SEEBASEv2 database (FrOG Tech, 2007) was used to estimate the depth-to-basement[1] value of 8,000 m beneath Browse Island-1.

### *3.2. Basement lithology*

Adele Island-1 intersected a basement of Proterozoic quartzite. The lithology of the basement beneath Browse Island-1 was derived from the continuation of geophysical signatures (gravity and magnetics) from areas of known basement composition (Attachment B).

In this case, the closest well to intersect basement—Rob Roy-1, approximately 75 km northeast of Browse Island-1—penetrated quartzite (metasediments). The gravity and magnetic signatures of basement beneath Browse Island-1 suggest it is of a similar composition to the lithology intersected in Rob Roy 1. Basement data (actual and estimated) for Adele Island 1 and Browse Island 1is detailed in Attachment C.

[1] Rounded to the nearest 250 m.

# 4. Heat flow modelling methodology

### *4.1. Introduction*

1D conductive heat flow modelling allows for accurate extrapolation of temperature to depth as it honours the thermodynamic principles of heat transfer. The depth to which temperature can be extrapolated depends on the depth to which the assumption of purely vertical conductive heat transfer holds true. The assumption fails if a) there is a component of advective heat transfer via fluid flow, b) there is appreciable lateral conduction of heat, or c) temperatures exceed about 300°C, at which point radiation starts to play a role in heat transfer. This report assumes purely vertical conductive heat transfer with internal heat generation over the modelled depth intervals.HDR was commissioned to investigate the thermal conditions of two wells in the Browse Basin based on existing temperature data. HDR used its proprietary 1D conductive heat flow modelling software to build heat flow models for each well. Required data include downhole temperatures (corrected to approximate equilibrated conditions where sufficient information is available) and thermal conductivity data of intersected formations. Raw temperature and lithological data were provided by the DMP.

### *4.2. Heat flow and limitations of 1D modelling*

Surface heat flow is a measure of the flux of thermal power at surface and is a function of the rate of heat generated within the crust plus heat conducted from the mantle.

The principle aim of geothermal exploration is to locate anomalously high temperatures at an economically and technically viable drilling depth. The thermal state of the crust can be expressed at the surface in the form of heat flow units (mW/$m^2$) and it is generally assumed that heat is transported to the surface by conductive means. In a conductive heat regime the temperature, **T**, at depth, **z**, is equal to the surface temperature, $\mathbf{T_0}$, plus the product of heat flow, **Q**, and thermal resistance, **R**, such that:

$\mathbf{T=T_0+QR}$, where **R**=**z**/(average thermal conductivity between the surface and **z**).

Consequently, the most prospective regions for geothermal exploration are those that have geological units of sufficiently low conductivity (high thermal resistance) in the cover sequence combined with high heat flow.

Heat flow is the product of temperature gradient and rock thermal conductivity. It is therefore calculated, or modelled, from these two parameters, not directly measured. The modelling of heat flow is a precision skill that requires experience and a detailed understanding of physical conditions in the borehole and the physical properties of the rocks; including advective processes such as ground water flow or borehole convection that may influence bore temperature (such as ground water flow or borehole convection), and the temperature dependence of conductivity.

Heat flow estimates are only as accurate as the data that have been used to generate them. It is therefore important that the temperature and conductivity data used to model heat flow represent as closely as possible the actual thermal conditions.

HDR's 1D conductive heat flow modelling software accounts for heat generation and the temperature dependence of conductivity. However, the results of 1D heat flow modelling should be treated with caution when extrapolating data spatially over considerable distance as thermal properties almost certainly change with facies variation laterally.

### *4.3. Verification of well temperatures*

Temperature interpolations and extrapolations based solely on reported well temperatures measured during the drilling process are liable to underestimate the true virgin rock temperature of the formations at depth due to the cooling effect of circulating drilling mud. To ensure the most accurate thermal modelling, corrections (such as Horner Plots) are applied to time series data recorded during logging processes.

The Horner Plot method corrects the bore hole temperature for the cooling effect of the drilling process using the parameters of recorded bore hole temperature, the time elapsed since the last fluid circulation, and the time between the end of drilling and the cessation of fluid circulation. The accuracy of the correction depends on the reliability and accuracy of the reported temperatures and times. More than one recorded temperature from the same depth, but at different times, is required for a Horner Plot.

Temperatures reported in the well completion reports of the two wells in the Browse Basin were assessed and, where sufficient information was found, Horner corrections were applied using the methodology of Hermanrud *et al*. (1990). The corrected temperatures were used in the thermal models for these wells. For other temperature data it was not possible to apply corrections. Uncertainty values were ascribed to each temperature datum, as detailed in Section 5.2.

Temperature data used for each well model, and the status of those data (corrected or uncorrected), are itemised with the individual heat flow models in Appendix 1.

### *4.4. Surface temperatures*

Ground surface temperature is an important constraint for heat flow models defined by limited downhole temperature data. Average surface temperature for each well was estimated from mean annual air temperature data reported by the Australian Bureau of Meteorology for the Browse Basin (Kuri Bay weather station). Ground surface temperature was assumed to be 3°C hotter due to surface insulation, following the findings of Howard and Sass (1964). Uncertainty was assumed to be ± 1.5°C. Estimated ground surface temperatures for each well are shown within the individual heat flow models (Appendix 1).

### *4.5. Rock thermal conductivity measurement*

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.

HDR undertook steady-state thermal conductivity measurements of four representative samples from lithologies of the Browse Basin using HDR's portable electronic divided bar apparatus. Samples came from core stored at the DMP core library in Perth. The full conductivity report is provided in Appendix 2 and a summary of measurements is provided in Attachment D.

The limited number of specimens measured reflects the limited core available for testing.

### *4.6. Rock thermal conductivity estimation*

Since the well completion reports and DMP formation tops database only record ages and lithologies in the two wells, and none of the samples from formations tested in HDR's thermal conductivity analysis were intersected by these two wells, it was necessary for HDR to allocate thermal conductivity values based on similar aged lithologies in the adjacent Carnarvon and Canning basins. As rock thermal conductivity is highly dependent upon lithology, an uncertainty of 20% was assigned to each uncertainty to reflect this.

Thermal conductivity values for each Browse Basin formation used in the 1D heat flow models are shown in Table 1 and Attachment E.

**Table 1:** Thermal conductivities by formation for the Browse Basin, as used for 1D heat flow modelling in this report. The full HDR thermal conductivty report is included as Appendix 2 of this report.

| Formation | Conductivity (W/mK) | Uncertainty ±(W/mK) |
|---|---|---|
| Miocene/Pliocene lst (?Barracouta/Oliver Fm) | 1.68 | 0.34 |
| Upper Cretaceous glauconitic sst/slt/mst (?Puffin/ Prudhoe Fm) | 2.26 | 0.45 |
| Lower Cretaceous sst (?Echuca Shoals Fm) | 2.83 | 0.57 |
| Upper Jurassic glauconitic sst/slt/dolomite (?Upper Vulcan Fm) | 2.70 | 0.54 |
| Upper Jurassic glauconitic sst/slt/lignite (?Upper Vulcan Fm) | 1.15 | 0.23 |
| Proterozoic quartzite | 6.00 | 1.20 |

### 4.7. Estimating basement heat generation

Heat generation is most effectively estimated from the analytical measurement of uranium, thorium and potassium within rock samples. As it was not possible to obtain basement samples for analytical measurement, HDR assessed the heat generation of rocks within and adjacent to the Browse Basin using data from the Geoscience Australia geochemical data base (OZCHEM, 2007). Heat generation values estimated from these data have been incorporated into the 1D heat flow models for this study.

As no geochemical data were available for the Browse Basin, data from the Kimberley region and Halls Creek Orogen were utilised as proxies, assuming that similar rocks may partly comprise the basement of the Browse Basin. Heat generation ($\mu W/m^3$) was estimated using an assumed rock density and the isotopic abundance method as described in Beardsmore and Cull (2001). Individual results for metasedimentary rocks are listed in Attachment F.

Median heat generation results for metasedimentary rock samples adjacent to the Browse Basin are shown in Table 2. The median values are based on a relatively small number of samples, and are likely to change with further geochemical sampling of basement rocks beneath the Browse Basin. The data suggest that the heat generating potential of metasedimentary rocks around the Browse Basin is not greatly elevated.

**Table 2:** Summary of heat generation estimates for metasedimnentary rocks around the Browse Basin

| Lithology | Number of samples | Assumed density ($g/cm^3$) | Heat generation ($\mu W/m^3$) Range | Heat generation ($\mu W/m^3$) Median |
|---|---|---|---|---|
| Metasedimentary | 3 | 2.48 | 1.22-6.38 | 3.45 |

# 5. Heat flow modelling

### *5.1. Estimated heat flow*

HDR constructed 1D conductive heat flow models (Figure 5) for the two wells in the Browse Basin (the individual details of these thermal models are shown in Appendix 1). A summary of heat flow results, and the relative reliability ranking of these data, is shown in Attachment G. HDR incorporated temperature data, rock thermal conductivity data and heat generating potential estimates to model heat flow in the two wells. Heat flow was adjusted until the predicted temperature profile best fit the reported temperature datasets.

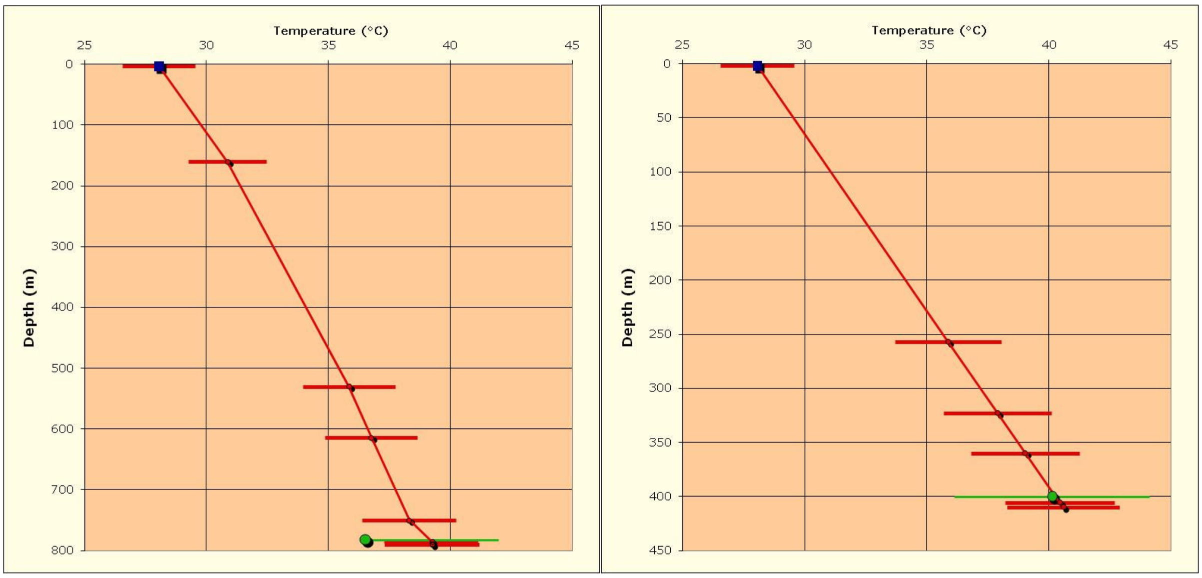


**Figure 5:** 1D heat flow models for the Adele Island-1 (left) and Browse Island-1 (right) petroleum wells. The green circles represent individual temperature data; the green lines represent the degree of uncertainty; the red line is the predicted temperature profile for a heat flow of 30 ± 3.3 mW/m$^2$ and 51 ± 6.8 mW/m$^2$, respectively.

### *5.2. Reliability of heat flow data*

Modelled heat flow is highly dependent upon the quality and quantity of temperature data. For each temperature datum, an uncertainty range was estimated based on the type of datum and the information known about it. The Horner corrected value from Browse Island-1 was assigned a relatively narrow uncertainty range centred on the corrected value. The uncorrected BHT value from Adele Island-1, however, was assigned a zero uncertainty on the 'negative' side and a much larger uncertainty on the 'positive' side to reflect the fact that this measurement very likely understated the true temperature conditions. Heat flow models were constructed so that predicted temperature profiles passed as near as possible through the mid-point of the error bars on the temperature data.

Modelled heat flow values were ascribed a relative reliability ranking based on a qualitative assessment of the well temperature data (Table 3 and Attachment G).

**Table 3:** Reliability ranking scheme for the two wells modelled in the Browse Basin

| Reliability Ranking | Most Reliable Temperature Data |
|---|---|
| 1 | One BHT datum |
| 2 | Several BHT data |
| 3 | One DST or Horner corrected temperature |
| 4 | Several DST or Horner corrected temperatures |
| 5 | Both DST and Horner corrected temperatures |

# 6. Conclusions

The measured rock thermal conductivities for the four core samples collected range between 2.29–4.51 W/mK. Apparent heat flow values for the two Browse Basin wells were 30 ± 3.3 $mW/m^2$ and 51 ± 6.8 $mW/m^2$. The limit of just two data points over the entire Browse Basin makes it impossible to draw any firm conclusions about the broader distribution of heat flow across the region.

The limited well penetrations and seismic data in the shallow water sections of the Browse Basin would suggest that the potential to exploit geothermal energy in the Browse Basin remains highly uncertain.

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**Attachment A:** Wells in the Browse Basin that form this study.

| Well Name | Area | Well ID | Well Status | Total Depth (m) | Deviated well? | Age at Total Depth | Lithostratigraphic Unit | Datum | Latitude (°) | Longitude (°) |
|---|---|---|---|---|---|---|---|---|---|---|
| Adele Island 1 | Leveque Shelf | W001086 | Petroleum | 789.5 | N | Proterozoic | Quartzite | GDA94 | -15.511099 | 123.158219 |
| Browse Island 1 | Caswell Sub-basin | W001490 | Stratigraphic | 405.5 | N | Pliocene | Argillaceous lst | GDA94 | -14.111149 | 123.550458 |

**Attachment B:** Basement lithology and depths for all wells in the Browse Basin that intersected basement.

| Well Name | Datum | Latitude (°) | Longitude (°) | TD (m) | Basement type | Depth to Basement (m) |
|---|---|---|---|---|---|---|
| Adele Island 1 | GDA94 | -15.511099 | 123.158219 | 789.5 | Quartzite | 785 |
| Capsule 1/ST1 | GDA94 | -13.655464 | 124.506232 | 1089 | Gabbro | 1087 |
| Cilia 1 | GDA94 | -13.594924 | 125.074506 | 498 | Rhyodacite | 497 |
| Cornea 1 | GDA94 | -13.695665 | 124.492046 | 830 | Porphyritic dacite | 827.8 |
| Cornea 1B | GDA94 | -13.698648 | 124.494902 | 980 | Quartzite | 978 |
| Cornea South 1 | GDA94 | -13.763531 | 124.461452 | 847 | Rhyolite | 825.9 |
| Cortex 1 | GDA94 | -13.669817 | 124.790733 | 462.5 | Quartzite | 432.5 |
| Hammer 1 | GDA94 | -13.663217 | 124.515428 | 944 | Granite (SWC); Rhyolite (cuttings) | 917 |
| Intrepid 1 | GDA94 | -12.932569 | 125.848940 | 1394 | Granite (minor quartz veining) | 1381 |
| Leveque 1 | GDA94 | -15.751918 | 122.006186 | 899.5 | Gabbro | 895.8 |
| Londonderry 1 | GDA94 | -13.613356 | 124.513087 | 1145 | Metasomatised, strongly porphyritic rhyodacite | 1135 |
| Retina 1 | GDA94 | -13.352069 | 125.198051 | 611 | Rhyolite | 596 |
| Rob Roy 1 | GDA94 | -13.969584 | 124.200463 | 2286 | Quartzite | 2255.5 |
| Stroma 1 | GDA94 | -13.779439 | 124.562635 | 674 | Granodiorite | 673 |
| Strumbo 1 | GDA94 | -13.228039 | 125.497814 | 728 | Rhyolite | 705 |
| Tear 1 | GDA94 | -13.580525 | 124.593720 | 887 | Rhyolite | 847 |

**Attachment C:** Basement (predicted and actual) lithology and depths for the wells in this study.

| Well Name | Well ID | Total Depth (m) | Basement Lithology | Basement Depth (m) | Depth to Basement Beneath Total Depth (m) | Datum | Latitude (°) | Longitude (°) |
|---|---|---|---|---|---|---|---|---|
| Adele Island 1 | W001086 | 789.5 | Quartzite | 785 | - | GDA94 | -15.511099 | 123.158219 |
| Browse Island 1 | W001490 | 405.5 | Metasediment | 8000 | 7594.5 | GDA94 | -14.111149 | 123.550458 |

**Attachment D:** Summary of measured rock thermal conductivity data for the Browse Basin (see Appendix 2).

| Sample | Well | Depth from (m) | Depth to (m) | Conductivity (W/mK) | Uncertainty ± (W/mK) | Formation | Lithology |
|---|---|---|---|---|---|---|---|
| DIR146 | Calliance 1 | 3776.0 | 3776.3 | 3.33 | 0.15 | Montara Formation | heterolithic fine-grained yellow/buff sst and dark grey slt; highly bioturbated; occasional reddish brown nodules/diagenetic overprint? |
| DIR147 | Brecknock 2 | 3786.8 | 3787.0 | 4.51 | 0.10 | Plover Formation | yellow fine-grained sst |
| DIR148 | Calliance 1 | 3797.2 | 3797.4 | 2.82 | 0.12 | Plover Formation | grey slt; mottled [bioturbated] |
| DIR149 | Brecknock 2 | 3825.7 | 3825.9 | 2.29 | 0.17 | Nome Formation | dark grey slt; highly fractured [healed? Doubtful drilling induced?] |

**Attachment E:** Formation conductivities for the Browse Basin used in the 1D heat flow models. Notes refer to other reports generated by HDR for this same project.

| Formation | Conductivity (W/mK) | Uncertainty ± (W/mK) | Notes |
|---|---|---|---|
| Miocene/Pliocene lst (?Barracouta Formation/Oliver Formation) | 1.68 | 0.34 | Use HDRa (2010): Gippsland Limestone |
| Upper Cretaceous glauconitic sst/slt/mst (?Puffin Formation/Prudhoe Formation) | 2.26 | 0.45 | Use HDRb (2010): Windalia Sandstone Member - Muderong Shale - Winning Group |
| Lower Cretaceous sst (?Echuca Shoals Formation) | 2.83 | 0.57 | Use HDRb (2010): Birdrong Sandstone - Winning Group |
| Upper Jurassic glauconitic sst/slt/dolomite (?Upper Vulcan Formation) | 2.70 | 0.54 | Use Driscoll et al., 2009: Alexander Formation |
| Upper Jurassic glauconitic sst/slt/lignite (?Upper Vulcan Formation) | 1.15 | 0.23 | Use HDRb (2010): Dingo Claystone |
| Proterozoic quartzite | 6.00 | 1.20 | Use Beardsmore & Cull, 2001 |

**Attachment F:** Estimated heat generation for metasedimentary rock samples adjacent to the Browse Basin. $K_2O$, U and Th data from OZCHEM (2007).

| Region | Province | Latitude (°) | Longitude (°) | Datum | Lithname | Description | $K_2O$ by weight % | K (ppm) | U (ppm) | Th (ppm) | Average assumed density ($g/cm^3$) | Heat generation from isotopic abundance ratios ($\mu W/m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | Halls Creek Orogen | -17.485641 | 125.360307 | GDA94 | sediment | clastic sediment | 2.11 | 17500 | 2 | 9 | 2.48 | 1.22 |
| Kimberley Region | Kimberley Basin | -17.121569 | 125.364118 | GDA94 | conglomerate | clastic sediment | 1.31 | 10900 | 5 | 78 | 2.48 | 6.38 |
| Kimberley Region | King Leopold Orogen | -16.530348 | 123.707906 | GDA94 | arkose | arkose | 0.39 | 3200 | 8 | 23 | 2.48 | 3.45 |

| | |
|---|---|
| **Median** | **3.45** |

**Attachment G:** Modelled heat flow values and estimates of reliability for wells in the Browse Basin.

| Well Name | Total Depth (m) | Basement Lithology | Depth to Basement (m) | Depth from Total Depth to Basement (m) | Datum | Latitude (°) | Longitude (°) | DST Temp Data (y/n) | Horner Temp Data (y/n) | Overall Reliability (1 lowest to 5 highest) | Heat Flow ($mW/m^2$) | Uncertainty ± ($mW/m^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adele Island 1 | 789.5 | Quartzite | 785 | - | GDA94 | -15.511099 | 123.158219 | n | n | 1 | 30 | 3.3 |
| Browse Island 1 | 405.5 | Metasediment | 8000 | 7594.5 | GDA94 | -14.111149 | 123.550458 | n | y | 3 | 51 | 6.8 |

# Appendix 1

# Heat flow models and temperature data used for two wells in the Browse Basin Report DMP0260909

HDR

July 2010

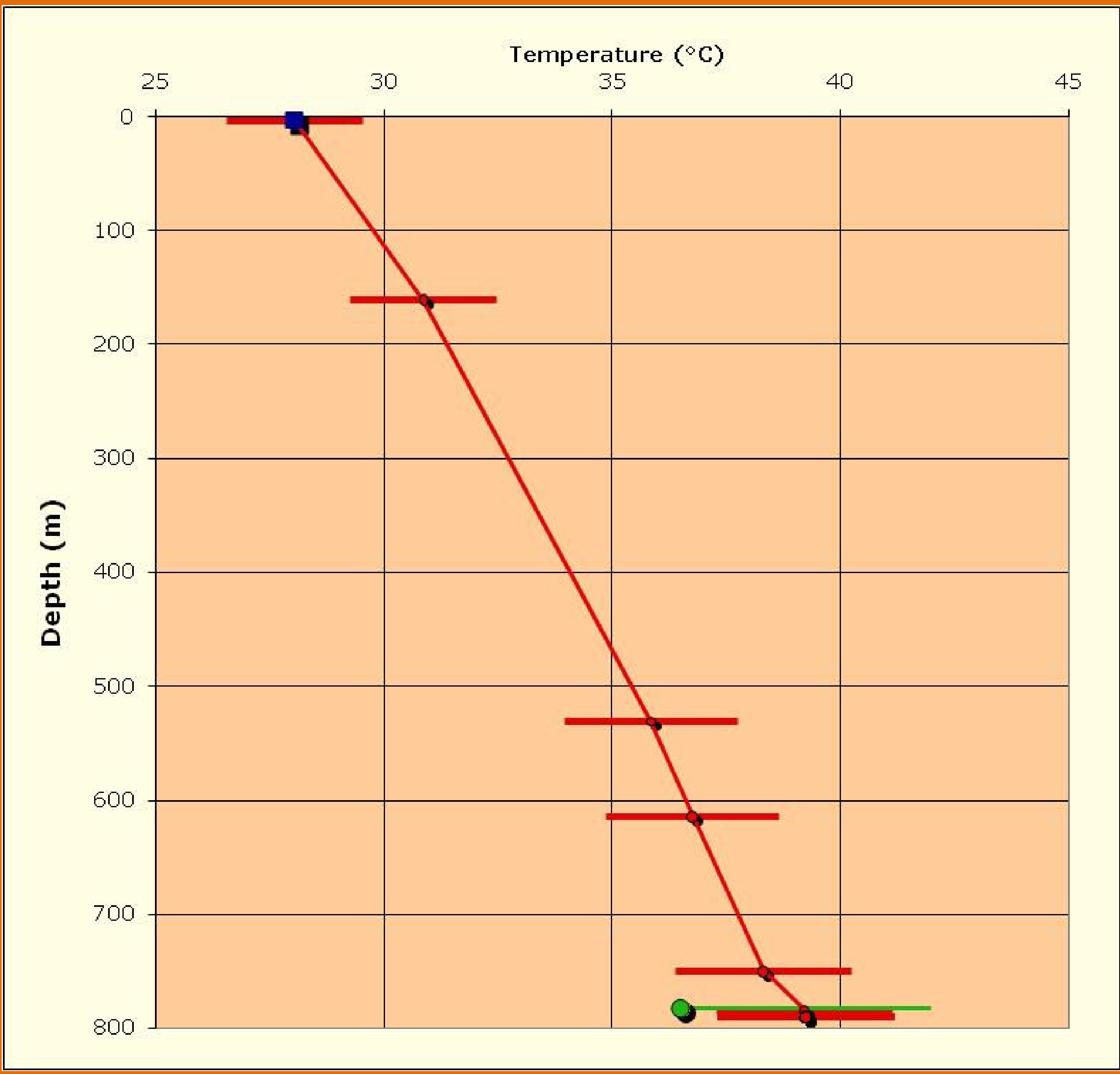
An appendix to the report - Geothermal Energy Potential in Selected Areas of Western Australia (Browse Basin); prepared for the Department of Mines and Petroleum, Western Australia.

| | | | | | |
|---|---|---|---|---|---|
| Number of layers | 7 | Up to 50 | **Heat flow:** | 30 ± 3.3 mW/m2 | |
| "Depth" to ground level | 3 | "KB height" | | | |
| Total Depth (m) | 790 | From driling datum | | | |
| Surface temp. (°C) | 28.05 | **Adele Island 1** | | | |
| Uncertainty in surface T | 1.5 | ±°C | | | |

| | Formation Name | Top (m) | Cond @ 30°C (W/mK) | A (µW/m³) | Thickness (m) |
|---|---|---|---|---|---|
| 1 | Miocene/Pliocene lst (?Barracouta/Oliver Fm) | 3 | 1.68 ± 0.34 | 0 | 157 |
| 2 | Upper Cretaceous glauconitic sst/slt/mst (?Puffin/Prudhoe Fm) | 160 | 2.26 ± 0.45 | 0 | 370 |
| 3 | Lower Cretaceous sst (?Echuca Shoals Fm) | 530 | 2.83 ± 0.57 | 0 | 84 |
| 4 | Upper Jurassic glauconitic sst/slt/dolomite (?Upper Vulcan Fm) | 614 | 2.70 ± 0.54 | 0 | 136 |
| 5 | Upper Jurassic lignite/sst (?Upper Vulcan Fm) | 750 | 1.15 ± 0.23 | 0 | 35 |
| 6 | Proterozoic quartzite | 785 | 6.00 ± 1.20 | 0 | 4.5 |
| 7 | Proterozoic quartzite | 789.5 | 6.00 ± 1.20 | 0 | 0.5 |

**Downhole temperature data (°C):**

| Depth (m) | Value | -uncert | +uncert | Comment: |
|---|---|---|---|---|
| 782 | 36.5 | 0 | 5.474 | BHT from Temp Log [time since circ. unknown] |



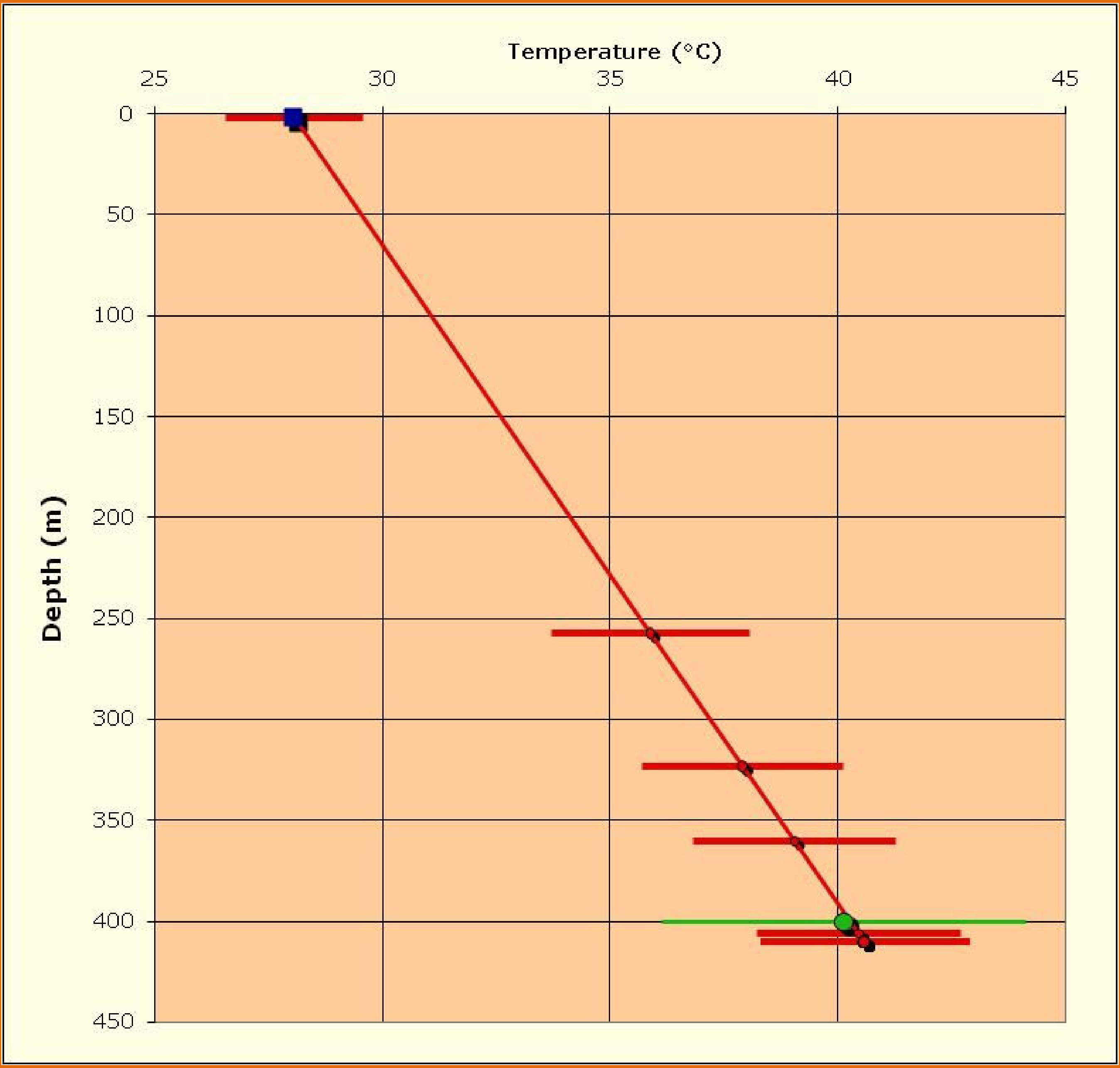

# Adele Island 1

| | | | | |
|---|---|---|---|---|
| Number of layers | 5 | Up to 50 | **Heat flow:** | 51 ± 6.8 mW/m2 |
| "Depth" to ground level | 1.5 | "KB height" | | |
| Total Depth (m) | 410 | From driling datum | | |
| Surface temp. (°C) | 28.05 | **Browse Island 1** | | |
| Uncertainty in surface T | 1.5 | ±°C | | |

| | Formation Name | Top (m) | Cond @ 30°C (W/mK) | A (μW/m³) | Thickness (m) |
|---|---|---|---|---|---|
| 1 | Pleistocene lst (?Barracouta Fm) | 1.5 | 1.68 ± 0.34 | 0 | 255.5 |
| 2 | Pleistocene marl (?Barracouta Fm) | 257 | 1.68 ± 0.34 | 0 | 66 |
| 3 | Pleistocene lst (?Barracouta Fm) | 323 | 1.68 ± 0.34 | 0 | 37 |
| 4 | Pliocene argillaceous lst (?Barracouta Fm) | 360 | 1.68 ± 0.34 | 0 | 45.5 |
| 5 | Pliocene argillaceous lst (?Barracouta Fm) | 405.5 | 1.68 ± 0.34 | 0 | 4.5 |

**Downhole temperature data (°C):**

| Depth (m) | Value | -uncert | +uncert | Comment: |
|---|---|---|---|---|
| 399.83 | 40.12 | 4 | 4 | Horner [3 values] |




**Browse Island 1**

# Appendix 2

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# Thermal conductivity of core samples DIR089-DIR207

An appendix to the report Geothermal Energy Potential in Selected Areas of Western Australia (Browse Basin)

Prepared for the Department of Mines and Petroleum , Western Australia

July 2010

# Executive Summary

The Western Australian Department of Mines and Petroleum (DMP) commissioned Hot Dry Rocks Pty Ltd (HDR) to measure the thermal conductivity of 119 rock specimens collected from the DMP Perth Core Library and Geoscience Australia Canberra Core Library in April 2010. These specimens came from the Bonaparte, Browse, Carnarvon and Officer basins. Measurements were made on the 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 30°C. The uncertainties are dependent upon sample quality and preparation method..

HDR 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. 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.

The Western Australian Department of Mines and Petroleum (DMP) commissioned Hot Dry Rocks Pty Ltd (HDR) to undertake heat flow modelling in the Bonaparte, Browse, Carnarvon, and Officer basins. HDR collected 119 specimens[1] from the DMP Perth Core Library and Geoscience Australia Canberra Core Library in April 2010 (Table 1). Thermal conductivity measurements were made on 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 (e.g. Vosteen and Schellschmidt, 2003[2]), 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 HDR, while "sample" refers to part of a specimen prepared for conductivity measurement. In general, three samples are prepared from each specimen.

[2] **Vosteen, H.-D. and Schellschmidt, R.** (2003). Influence of temperature on thermal conductivity, thermal capacity and thermal diffusivity for different types of rock. *Physics and Chemistry of the Earth*, 28, 499–509.

**Table 1**. Specimens presented for thermal conductivity measurement.

| Well | Basin | Formation | Lithology | Depth From (m) | Depth To (m) | Depth From (') | Depth To (') | HDR sample ID |
|---|---|---|---|---|---|---|---|---|
| Coburn 1 | Carnarvon | Toolonga Calcilutite | light grey marl | 73.70 | 73.92 | | | DIR089 |
| Coburn 1 | Carnarvon | Birdrong Sandstone | light brown carbo-naceous fine-grained sst | 172.70 | 172.85 | | | DIR090 |
| Coburn 1 | Carnarvon | Kopke Sandstone | grey light brown sst with finely laminated | 212.70 | 212.85 | | | DIR091 |
| Coburn 1 | Carnarvon | Kopke Sandstone | red bed sst finely laminated, similar to DIR091 but red | 404.40 | 404.55 | | | DIR092 |
| Coburn 1 | Carnarvon | Kopke Sandstone | red/green/grey mottled slt/cst - differing oxidising regimes | 475.40 | 475.50 | | | DIR093 |
| Coburn 1 | Carnarvon | Faure Formation | bioturbated grey/red/brown cst | 564.60 | 564.80 | | | DIR094 |
| Coburn 1 | Carnarvon | Coburn Formation, Dirk Hartog Group | blue/grey (light and dark lamina-tions) dolomitic cst | 616.70 | 616.85 | | | DIR095 |
| Coburn 1 | Carnarvon | Coburn Formation, Dirk Hartog Group | blue/grey (light and dark lamina-tions) dolomitic cst | 685.50 | 685.65 | | | DIR096 |
| Coburn 1 | Carnarvon | Yaringa Formation, Dirk Hartog Group | blue/grey (light and dark banding) dolomitic cst/slt | 794.40 | 794.65 | | | DIR097 |
| Coburn 1 | Carnarvon | Ajana Formation, Dirk Hartog Group | blue/grey (light and dark lamina-tions) dolomitic cst | 893.75 | 893.90 | | | DIR098 |
| Coburn 1 | Carnarvon | Marron Member, Ajana Formation | dark blue/grey cst | 920.30 | 920.45 | | | DIR099 |
| Coburn 1 | Carnarvon | Marron Member, Ajana Formation | pale tan cst with numerous grey salt patches | 951.70 | 951.90 | | | DIR100 |
| Coburn 1 | Carnarvon | Tumblagooda Sandstone | dark brown/red slt beds [10% of cored interval] | 1011.40 | 1011.65 | | | DIR101 |
| Coburn 1 | Carnarvon | Tumblagooda Sandstone | pale pink to pink-red medium-grained to granule sst [90% of cored interval]; predom quartz and orthoc-lase grains | 1030.00 | 1030.20 | | | DIR102 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Coburn 1 | Carnarvon | Windalia Sandstone Member | sst [friable] | 150.80 | 151.00 | | | DIR103 |
| Coburn 1 | Carnarvon | Muderong Shale | mst | 166.30 | 166.50 | | | DIR104 |
| GSWA Ballythanna 1 | Carnarvon | Keogh Formation | medium-grained to granule sst common cross beds | 35.90 | 36.10 | | | DIR105 |
| GSWA Ballythanna 1 | Carnarvon | Ballythanna Sandstone Member | light tan fine-grained to medium-grained sst [50% of cored interval] | 131.90 | 132.05 | | | DIR106 |
| GSWA Ballythanna 1 | Carnarvon | Ballythanna Sandstone Member | fine-grained sst with common carbonaceous flaser interbeds, whisps and slumped layers; pyritic; bioturbated [50% of cored interval] | 292.30 | 292.43 | | | DIR107 |
| GSWA Ballythanna 1 | Carnarvon | Callytharra Formation | dark grey very fossiliferous shale | 358.75 | 358.90 | | | DIR108 |
| GSWA Ballythanna 1 | Carnarvon | Lyons Group | fine-grained sst cream coloured | 397.55 | 397.70 | | | DIR109 |
| GSWA Ballythanna 1 | Carnarvon | Lyons Group | light grey fine-grained sst with common flaser beds of dark grey slt | 453.40 | 453.55 | | | DIR110 |
| GSWA Ballythanna 1 | Carnarvon | Lyons Group | dark grey interbedded slt/fine-grained sst | 461.70 | 461.85 | | | DIR111 |
| Giralia 1 | Carnarvon | Billidee Formation | dark grey slt, fine-grained sst heterolithic | 682.10 | 682.22 | | | DIR112 |
| Giralia 1 | Carnarvon | Cordalia Formation | dark grey cst? | 919.00 | 919.10 | | | DIR113 |
| Kennedy Range 1 | Carnarvon | Coolkilya Sandstone | tan grey medium-grained sst | | | 1530' | 1530' 9" | DIR114 |
| Kennedy Range 1 | Carnarvon | Baker Formation | reddish brown medium-grained sst | | | 2005' | 2005' 9" | DIR115 |
| Kennedy Range 1 | Carnarvon | Nalbia Sandstone | brown medium-grained sst, occasional bioturbation | | | 2015' 6" | 2016' 3" | DIR116 |
| Kennedy Range 1 | Carnarvon | Wandagee Formation | dark brown slt/sst, heavily bioturbated | | | 2210' | 2210' 6" | DIR117 |
| Kennedy Range 1 | Carnarvon | Cundlego Formation | dark grey/light grey sst, finely laminated, pin stripe laminations [50% of cored interval] | | | 2817' | 2817' 9" | DIR118 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kennedy Range 1 | Carnarvon | Cundlego Formation | dark brown slt/sst, heavily biotur-bated [50% of cored interval] | | | 2819' 6" | 2820' 3" | DIR119 |
| Kennedy Range 1 | Carnarvon | Bulgadoo Shale | brown slt | | | 4163' 6" | 4164' 3" | DIR120 |
| Kennedy Range 1 | Carnarvon | Mallens Sandstone | dark grey/light grey sst, finely laminated, pin stripe laminations [25% of cored interval] | | | 4711' | 4711' 6" | DIR121 |
| Kennedy Range 1 | Carnarvon | Mallens Sandstone | dark brown slt/sst, heavily biotur-bated [75% of cored interval] | | | 5104' | 5104' 9" | DIR122 |
| Kennedy Range 1 | Carnarvon | Coyrie Formation | brown sst, minor bioturbation | | | 5484' 3" | 5484' 10" | DIR123 |
| Kennedy Range 1 | Carnarvon | Coyrie Formation | pale pink/tan sst, no bioturbation | | | 5537' 3" | 5538' | DIR124 |
| Linda 2 | Carnarvon | Dingo Claystone | dark grey cst/slt with thin stringers of light grey slt/sst - lenticular bed-ding | 2814.80 | 2815.05 | | | DIR125 |
| Kennedy Range 1 | Carnarvon | Moogooloo Sandstone | light tan grey coarse-grained sst with minor carbo-naceous flecks | | | 6606' | 6606' 9" | DIR126 |
| GSWA Barrabiddy 1A | Carnarvon | Nannyarra Sandstone | green grey mottled sst/slt | 781.70 | 781.95 | | | DIR127 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation | light grey fine-grained sst with rare slt flasers, some slumping in adjacent core | 773.90 | 774.10 | | | DIR128 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation | green-grey to light grey calcareous? Sst; highly fossili-ferous | 759.55 | 759.70 | | | DIR129 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation | light blue/grey lst with common stylolites | 669.35 | 669.55 | | | DIR130 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation | dark green/grey slt/cst | 616.90 | 617.10 | | | DIR131 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation | dark green/grey slt/cst; highly fos-siliferous | 617.65 | 617.90 | | | DIR132 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation; Point Maud Member | tan coloured lst; vugs/borings rare [10% of cored interval] | 551.75 | 551.95 | | | DIR133 |
| GSWA Barrabiddy 1A | Carnarvon | Gneudna Formation; Point Maud Member | tan coloured lst; ubiquitous vugs/borings [90% of cored interval] | 467.00 | 467.20 | | | DIR134 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GSWA Barrabiddy 1A | Carnarvon | Munabia Formation | light grey fine- to medium-grained sst with common flaser slt beds [~29 m = 34% of cored interval] | 213.20 | 213.45 | | | DIR135 |
| GSWA Barrabiddy 1A | Carnarvon | Munabia Formation | dark green/grey mst, mottled [~56 m = 66% of cored interval] | 246.25 | 246.40 | | | DIR136 |
| Quail 1 | Carnarvon | Yindagindy Formation | dark blue/grey calcareous mst | | | 8649' | 8649' 9" | DIR137 |
| Quail 1 | Carnarvon | Quail Formation | reddish brown medium-grained sst | | | 7319' | 7319' 9" | DIR138 |
| Onslow 1 | Carnarvon | Mungaroo Formation | grey mottled slt | | | 3781' 3" | 3782' | DIR139 |
| Onslow 1 | Carnarvon | Mungaroo Formation | pale grey/buff sst | | | 4279' 9" | 4280' 6" | DIR140 |
| Onslow 1 | Carnarvon | Locker Shale | light brown sst | | | 5706' | 5706' 9" | DIR141 |
| Onslow 1 | Carnarvon | Locker Shale | dark grey shale | | | 6631' | 6631' 9" | DIR142 |
| Learmonth 2 | Carnarvon | Learmonth Formation | cream medium-grained sst | | | 5375' | 5375' 9" | DIR143 |
| Pluto 3 | Carnarvon | Brigadier Formation | dark grey sly, highly bioturbated, thin whisps of fine-grained sst | 3056.70 | 3057.00 | | | DIR144 |
| Pluto 3 | Carnarvon | Brigadier Formation | heterolithic fine-grained yellow/buff sst and dark grey slt; occasional bioturbation | 3067.20 | 3067.50 | | | DIR145 |
| Calliance 1 | Browse | Montara Formation | heterolithic fine-grained yellow/buff sst and dark grey slt; highly bioturbated; occasional reddish brown nodules/diagenetic overprint? | 3776.00 | 3776.30 | | | DIR146 |
| Brecknock 2 | Browse | Plover Formation | yellow fine-grained sst | 3786.80 | 3787.00 | | | DIR147 |
| Calliance 1 | Browse | Plover Formation | grey slt; mottled [bioturbated] | 3797.20 | 3797.40 | | | DIR148 |
| Brecknock 2 | Browse | Nome Formation | dark grey slt; highly fractured [healed? Doubtful drilling induced?] | 3825.70 | 3825.90 | | | DIR149 |
| Yowalga 2 | Officer | Kanpa Formation | reddish finely laminated interbedded slt/sst; thick quartz veins | | | 2796' | 2796' 9" | DIR150 |
| Yowalga 2 | Officer | Kanpa Formation | cream to light grey finely laminated interbedded slt/sst | | | 3242' | 3242' 9" | DIR151 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bonaparte 1A | Bonaparte | Point Spring Sandstone | salmon pink medium-grained sst | | | 576' 4"/ 578' 4" | 576' 8"/ 578' 8" | DIR152 |
| Bonaparte 1A | Bonaparte | Tanmurra Formation | grey slt | | | 689' 8" | 690' | DIR153 |
| Bonaparte 2 | Bonaparte | Milligans Formation | heterolithic fine-grained light grey sst and dark grey slt; slumping features; whispy slt in the sst | | | 3948' 4"/ 3940' 4" | 3948' 8"/ 3940' 8" | DIR154 |
| Bonaparte 1A | Bonaparte | Burt Range Formation | heterolithic fine-grained cream sst and greenish grey slt | | | 9267' 4"/ 9263' 4" | 9267' 8"/ 9263' 8" | DIR155 |
| Bonaparte 1A | Bonaparte | Cockatoo Group | ?grey quartzite | | | 10476' 4" | 10476' 8" | DIR156 |
| Laminaria East 1 | Bonaparte | Frigate Shale | grey shale | 3249.70 | 3249.90 | | | DIR157 |
| GSWA Barrabiddy 1A | Carnarvon | Gearle Siltstone | dark grey friable mst | 66.00 | 66.30 | | | DIR158 |
| GSWA Barrabiddy 1A | Carnarvon | Windalia Radiolarite | grey mst, not dense | 127.75 | 127.95 | | | DIR159 |
| GSWA Barrabiddy 1A | Carnarvon | Windalia Sandstone Member | green slt to fine-grained sst; glauconitic | 157.30 | 157.45 | | | DIR160 |
| Turtle 1 | Bonaparte | Bonaparte Formation | grey fine- to medium-grained sst | 2488.20 | 2488.50 | | | DIR161 |
| Turtle 1 | Bonaparte | Keyling Formation | sst, oil impregnated; no non oil sands within core | 929.00 | 929.30 | | | DIR162 |
| Turtle 1 | Bonaparte | Keyling Formation | heterolithic dark grey slt/light grey sst; whispy slt | 932.45 | 932.70 | | | DIR163 |
| Turtle 1 | Bonaparte | Treachery Shale | interbedded light grey sst and dark grey slt | 1441.65 | 1441.85 | | | DIR164 |
| Turtle 1 | Bonaparte | Kuriyippi Formation | light grey sst | 1599.65 | 1599.95 | | | DIR165 |
| Turtle 1 | Bonaparte | Kuriyippi Formation | light grey sst and dark grey slt; mottled/bioturbated | 1601.50 | 1601.75 | | | DIR166 |
| Turtle 1 | Bonaparte | Kuriyippi Formation | grey diamictite? | 1612.00 | 1612.30 | | | DIR167 |
| GSWA Empress 1A | Officer | Lennis Sandstone | partially friable yellow medium-grained sst | 165.90 | 166.10 | | | DIR168 |
| GSWA Empress 1A | Officer | Paterson Formation | buff to tan medium-grained sst | 127.05 | 127.20 | | | DIR169 |
| GSWA Empress 1A | Officer | Paterson Formation | matrix supported pebble cgl; coarse-grained sst matrix | 116.15 | 116.40 | | | DIR170 |
| GSWA Empress 1A | Officer | Unnamed Sandstone | reddish brown medium-grained sst | 294.25 | 294.60 | | | DIR171 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GSWA Empress 1A | Officer | Paterson Formation | light grey slt | 106.70 | 107.00 | | | DIR172 |
| GSWA Empress 1A | Officer | Table Hill Volcanics | reddish grey basalt | 284.70 | 284.90 | | | DIR173 |
| GSWA Empress 1A | Officer | Wahlgu Formation | red cst | 367.80 | 368.00 | | | DIR174 |
| GSWA Empress 1A | Officer | Wahlgu Formation | red medium-grained sst | 351.80 | 352.00 | | | DIR175 |
| GSWA Empress 1A | Officer | Wahlgu Formation | dark brown cst chips | 431.50 | 431.70 | | | DIR176 |
| GSWA Empress 1A | Officer | Steptoe Formation | grey dolomite | 504.65 | 504.85 | | | DIR177 |
| GSWA Empress 1A | Officer | Steptoe Formation | dark brown cst chips | 603.80 | 604.00 | | | DIR178 |
| GSWA Empress 1A | Officer | Steptoe Formation | red sst | 568.30 | 568.50 | | | DIR179 |
| GSWA Empress 1A | Officer | Kanpa Formation | grey dolomite | 651.40 | 651.70 | | | DIR180 |
| GSWA Empress 1A | Officer | Kanpa Formation | light grey sst | 743.50 | 743.80 | | | DIR181 |
| GSWA Empress 1A | Officer | Kanpa Formation | mst | 805.90 | 806.10 | | | DIR182 |
| GSWA Empress 1A | Officer | Hussar Formation | interbedded mst/slt/sst | 931.00 | 931.30 | | | DIR183 |
| GSWA Empress 1A | Officer | Hussar Formation | sst | 1122.10 | 1122.40 | | | DIR184 |
| GSWA Empress 1A | Officer | Hussar Formation | mst | 1091.10 | 1091.30 | | | DIR185 |
| GSWA Empress 1A | Officer | Hussar Formation | dolomite | 1075.90 | 1076.20 | | | DIR186 |
| GSWA Empress 1A | Officer | Hussar Formation | mst/slt | 1223.30 | 1223.55 | | | DIR187 |
| GSWA Empress 1A | Officer | Browne Formation | halite | 1309.65 | 1309.80 | | | DIR188 |
| GSWA Empress 1A | Officer | Browne Formation | dolomite, slt | 1409.40 | 1409.55 | | | DIR189 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GSWA Empress 1A | Officer | Browne Formation | dolomite, slt | 1403.75 | 1403.95 | | | DIR190 |
| GSWA Empress 1A | Officer | Lefroy Formation | heavily fractured maroon to grey slt | 1531.70 | 1531.90 | | | DIR191 |
| GSWA Empress 1A | Officer | Basement | basalt | 1603.60 | 1603.80 | | | DIR192 |
| GSWA Empress 1A | Officer | Basement | dark grey/black finely laminated silty shale | 1558.90 | 1559.20 | | | DIR193 |
| Boondawari 1 | Officer | Mundadjini Formation | red cst | 302.20 | 302.40 | | | DIR194 |
| Boondawari 1 | Officer | Spearhole Formation | red sst | 613.30 | 613.50 | | | DIR195 |
| Boondawari 1 | Officer | Spearhole Formation | red slt/cst | 612.35 | 612.60 | | | DIR196 |
| Boondawari 1 | Officer | Table Hill Volcanics | dolerite | 1365.40 | 1365.60 | | | DIR197 |
| Boondawari 1 | Officer | Brassey Range Formation | interbedded red slt/sst | 834.60 | 834.80 | | | DIR198 |
| Boondawari 1 | Officer | Spearhole Formation | red slt | 349.60 | 349.80 | | | DIR199 |
| BMR Browne 1 | Officer | Bejah Claystone | salmon pink to cream cst with frequent pink-purple mottling; very light and almost porcelaneous | | | 30' 11" | 31' 7" | DIR200 |
| BMR Browne 1 | Officer | Samuel Formation | dark grey to yellow-grey laminated cst, slt and fine-grained sst; sulphorous, occasional bioturbation, micaceous, glauconite? | | | 325' | 325' 6" | DIR201 |
| BMR Browne 1 | Officer | Samuel Formation | reddish-brown to ochre slt, cst with finely laminated interbeds of whispy fine-grained sst | | | 192' 1" | 192' 7" | DIR202 |
| BMR Neale 1A-1B | Officer | Wanna Formation | tan fine-grained sst; occasional reddish brown mottling; feint cross-bedding | | | 369' 11" | 369' 11" | DIR203 |
| BMR Neale 1A-1B | Officer | McFadden Formation | grey to tan/grey fine-grained sst | | | 327' | 327' 7" | DIR204 |
| BMR Neale 1A-1B | Officer | McFadden Formation | brick red slt | | | 308' | 308' 9" | DIR205 |
| BMR Throssell 1 | Officer | Kanpa Formation | grey cst with abundant gypsum crystal; chicken-wire appearance? | | | 200' | 200' 10" | DIR206 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BMR Glenburgh 9 | Carnarvon | Madeline Formation | dark grey slt, cst; rare fossiliferous [graptolite?] | | | 192' | 192' 6" | DIR207 |

## 2. Methodology

Three sample preparation methods were undertaken to measure the thermal conductivity of specimens DIR089—DIR207, depending on specimen quality and quantity. In this report these three methods are referred to as 'Whole rock', 'Hollow cell, whole rock', or 'Hollow cell, matrix'. 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.

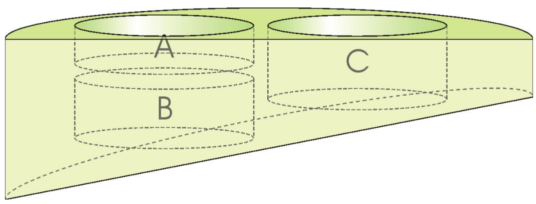
Where possible, three prisms were cut from each core specimen, each approximately ⅓ to ½ the length of the sample in thickness, and each sample was ground flat and polished. These are indicated on Table 2 by the description 'Whole rock'.

In cases where the core specimens were of a relatively unconsolidated lithology (such as clays, muds, and marls) showing significant susceptibility to deterioration during saturation, samples were prepared using hollow cells. These are indicated on Table 2 by the description 'Hollow cell, whole rock'.

In cases where the core specimens were either crushed or highly fragmented, making it impossible to measure the sample in its whole-rock state, thermal conductivity was measured as a matrix within a hollow cell with water. In such cases, the net conductivity of the rock matrix was calculated from the gross conductivity of the rock-water aggregate. These are indicated on table 2 by the description 'Hollow cell, matrix'. Colloquially, these samples are referred to as 'chips' or 'cuttings'.

All samples were evacuated under >95% vacuum for a minimum of three hours. Samples were then submerged in water prior to returning to atmospheric pressure. Saturation continued at atmospheric pressure for a minimum of twelve hours, and all samples were left submerged in water until just prior to conductivity measurement.

**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.



Samples were then measured for thermal conductivity measurement in a divided bar apparatus[3]. The thermal conductivity was measured along the long axis of the core provided for all samples prepared either as ‘Whole rock’ or ‘Hollow cell, whole rock’. Values were measured at a standard temperature of 30°C (± 2°C). Harmonic mean conductivity (Figure 1) and one standard deviation uncertainty were calculated for each specimen. Results are presented in the next section.

[3] 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. 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 ± 2% for non-friable whole rock samples (based on the instrument precision of the divided bar apparatus). Uncertainties for thermal conductivity measurements are shown in Table 2.

**Table 2.** Thermal conductivity of samples at 30°C, with well name, depth, uncertainty, sample type, and harmonic mean and uncertainty[4] for each specimen.

| Well | Depth From (m) | Depth To (m) | Depth From (') | Depth To (') | Uncer-tainty (%) | Sample type | HDR sample ID | | Conductivity (W/mK), harmonic mean, standard deviation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coburn 1 | 73.70 | 73.92 | | | 5 | Hollow cell, whole rock | DIR089 | A | 1.51 | 1.48 | ± | 0.03 |
| | | | | | | | | B | 1.46 | | | |
| | | | | | | | | C | 1.48 | | | |
| Coburn 1 | 172.70 | 172.85 | | | 5 | Hollow cell, whole rock | DIR090 | A | 2.49 | 2.47 | ± | 0.06 |
| | | | | | | | | B | 2.51 | | | |
| | | | | | | | | C | 2.40 | | | |
| Coburn 1 | 212.70 | 212.85 | | | 5 | Hollow cell, whole rock | DIR091 | A | 3.26 | 3.12 | ± | 0.19 |
| | | | | | | | | B | 3.22 | | | |
| | | | | | | | | C | 2.91 | | | |
| Coburn 1 | 404.40 | 404.55 | | | 3.5 | Whole rock | DIR092 | A | 3.57 | 3.64 | ± | 0.07 |
| | | | | | | | | B | 3.64 | | | |
| | | | | | | | | C | 3.70 | | | |
| Coburn 1 | 475.40 | 475.50 | | | 5 | Hollow cell, whole rock | DIR093 | A | 1.67 | 1.61 | ± | 0.06 |
| | | | | | | | | B | 1.61 | | | |
| | | | | | | | | C | 1.55 | | | |
| Coburn 1 | 564.60 | 564.80 | | | 3.5 | Whole rock | DIR094 | A | 2.12 | 2.14 | ± | 0.08 |
| | | | | | | | | B | 2.08 | | | |
| | | | | | | | | C | 2.22 | | | |
| Coburn 1 | 616.70 | 616.85 | | | 3.5 | Whole rock | DIR095 | A | 3.37 | 3.50 | ± | 0.17 |
| | | | | | | | | B | 3.69 | | | |
| | | | | | | | | C | 3.45 | | | |
| Coburn 1 | 685.50 | 685.65 | | | 3.5 | Whole rock | DIR096 | A | 2.48 | 2.53 | ± | 0.04 |
| | | | | | | | | B | 2.55 | | | |
| | | | | | | | | C | 2.55 | | | |
| Coburn 1 | 794.40 | 794.65 | | | 3.5 | Whole rock | DIR097 | A | 3.08 | 3.16 | ± | 0.08 |
| | | | | | | | | B | 3.17 | | | |
| | | | | | | | | C | 3.24 | | | |

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

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A | 2.34 | | | |
| Coburn 1 | 893.75 | 893.90 | | | 3.5 | Whole rock | DIR098 | B | 2.48 | 2.48 | ± | 0.15 |
| | | | | | | | | C | 2.65 | | | |
| | | | | | | | | A | 1.93 | | | |
| Coburn 1 | 920.30 | 920.45 | | | 3.5 | Whole rock | DIR099 | B | 1.95 | 2.00 | ± | 0.12 |
| | | | | | | | | C | 2.15 | | | |
| | | | | | | | | A | 3.99 | | | |
| Coburn 1 | 951.70 | 951.90 | | | 3.5 | Whole rock | DIR100 | B | 3.42 | 3.93 | ± | 0.57 |
| | | | | | | | | C | 4.55 | | | |
| | | | | | | | | A | 2.55 | | | |
| Coburn 1 | 1011.40 | 1011.65 | | | 3.5 | Whole rock | DIR101 | B | 2.70 | 2.65 | ± | 0.10 |
| | | | | | | | | C | 2.72 | | | |
| | | | | | | | | A | 2.99 | | | |
| Coburn 1 | 1030.00 | 1030.20 | | | 3.5 | Whole rock | DIR102 | B | 2.98 | 2.90 | ± | 0.14 |
| | | | | | | | | C | 2.75 | | | |
| | | | | | | | | A | 2.60 | | | |
| Coburn 1 | 150.80 | 151.00 | | | 5 | Hollow cell, whole rock | DIR103 | B | 2.57 | 2.56 | ± | 0.04 |
| | | | | | | | | C | 2.52 | | | |
| | | | | | | | | A | 1.64 | | | |
| Coburn 1 | 166.30 | 166.50 | | | 5 | Hollow cell, whole rock | DIR104 | B | 1.93 | 1.75 | ± | 0.15 |
| | | | | | | | | C | 1.70 | | | |
| | | | | | | | | A | 3.28 | | | |
| GSWA Ballythanna 1 | 35.90 | 36.10 | | | 3.5 | Whole rock | DIR105 | B | 2.80 | 3.24 | ± | 0.50 |
| | | | | | | | | C | 3.79 | | | |
| | | | | | | | | A | 3.15 | | | |
| GSWA Ballythanna 1 | 131.90 | 132.05 | | | 3.5 | Whole rock | DIR106 | B | 3.17 | 3.18 | ± | 0.05 |
| | | | | | | | | C | 3.24 | | | |
| | | | | | | | | A | 3.22 | | | |
| GSWA Ballythanna 1 | 292.30 | 292.43 | | | 3.5 | Whole rock | DIR107 | B | 3.02 | 3.21 | ± | 0.19 |
| | | | | | | | | C | 3.40 | | | |
| | | | | | | | | A | 1.61 | | | |
| GSWA Ballythanna 1 | 358.75 | 358.90 | | | 3.5 | Whole rock | DIR108 | B | 1.74 | 1.70 | ± | 0.08 |
| | | | | | | | | C | 1.75 | | | |
| | | | | | | | | A | 3.17 | | | |
| GSWA Ballythanna 1 | 397.55 | 397.70 | | | 3.5 | Whole rock | DIR109 | B | 3.03 | 3.08 | ± | 0.07 |
| | | | | | | | | C | 3.05 | | | |
| | | | | | | | | A | 2.87 | | | |
| GSWA Ballythanna 1 | 453.40 | 453.55 | | | 3.5 | Whole rock | DIR110 | B | 2.63 | 2.67 | ± | 0.17 |
| | | | | | | | | C | 2.55 | | | |
| | | | | | | | | A | 2.69 | | | |
| GSWA Ballythanna 1 | 461.70 | 461.85 | | | 3.5 | Whole rock | DIR111 | B | 2.38 | 2.56 | ± | 0.16 |
| | | | | | | | | C | 2.62 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Giralia 1 | 682.10 | 682.22 | | | 3.5 | Whole rock | DIR112 | A | 2.51 | 2.60 | ± | 0.30 |
| | | | | | | | | B | 2.97 | | | |
| | | | | | | | | C | 2.39 | | | |
| Giralia 1 | 919.00 | 919.10 | | | 3.5 | Whole rock | DIR113 | A | 1.91 | 1.98 | ± | 0.18 |
| | | | | | | | | B | 1.87 | | | |
| | | | | | | | | C | 2.19 | | | |
| Kennedy Range 1 | | | 1530' | 1530' 9" | 3.5 | Whole rock | DIR114 | A | 2.99 | 2.86 | ± | 0.11 |
| | | | | | | | | B | 2.79 | | | |
| | | | | | | | | C | 2.81 | | | |
| Kennedy Range 1 | | | 2005' | 2005' 9" | 3.5 | Whole rock | DIR115 | A | 3.51 | 3.51 | ± | 0.05 |
| | | | | | | | | B | 3.46 | | | |
| | | | | | | | | C | 3.55 | | | |
| Kennedy Range 1 | | | 2015' 6" | 2016' 3" | 3.5 | Whole rock | DIR116 | A | 2.98 | 2.99 | ± | 0.07 |
| | | | | | | | | B | 3.06 | | | |
| | | | | | | | | C | 2.93 | | | |
| Kennedy Range 1 | | | 2210' | 2210' 6" | 5 | Hollow cell, whole rock | DIR117 | A | 1.84 | 1.77 | ± | 0.14 |
| | | | | | | | | B | 1.62 | | | |
| | | | | | | | | C | 1.87 | | | |
| Kennedy Range 1 | | | 2817' | 2817' 9" | 3.5 | Whole rock | DIR118 | A | 3.13 | 2.93 | ± | 0.17 |
| | | | | | | | | B | 2.84 | | | |
| | | | | | | | | C | 2.84 | | | |
| Kennedy Range 1 | | | 2819' 6" | 2820' 3" | 3.5 | Whole rock | DIR119 | A | 2.40 | 2.23 | ± | 0.15 |
| | | | | | | | | B | 2.14 | | | |
| | | | | | | | | C | 2.16 | | | |
| Kennedy Range 1 | | | 4163' 6" | 4164' 3" | 3.5 | Whole rock | DIR120 | A | 1.23 | 1.27 | ± | 0.13 |
| | | | | | | | | B | 1.18 | | | |
| | | | | | | | | C | 1.43 | | | |
| Kennedy Range 1 | | | 4711' | 4711' 6" | 3.5 | Whole rock | DIR121 | A | 2.83 | 2.75 | ± | 0.14 |
| | | | | | | | | B | 2.59 | | | |
| | | | | | | | | C | 2.84 | | | |
| Kennedy Range 1 | | | 5104' | 5104' 9" | 3.5 | Whole rock | DIR122 | A | 2.53 | 2.64 | ± | 0.15 |
| | | | | | | | | B | 2.82 | | | |
| | | | | | | | | C | 2.60 | | | |
| Kennedy Range 1 | | | 5484' 3" | 5484' 10" | 3.5 | Whole rock | DIR123 | A | 2.37 | 2.29 | ± | 0.07 |
| | | | | | | | | B | 2.25 | | | |
| | | | | | | | | C | 2.26 | | | |
| Kennedy Range 1 | | | 5537' 3" | 5538' | 3.5 | Whole rock | DIR124 | A | 2.96 | 3.04 | ± | 0.09 |
| | | | | | | | | B | 3.15 | | | |
| | | | | | | | | C | 3.02 | | | |
| Linda 2 | 2814.80 | 2815.05 | | | 15 | Hollow cell, matrix | DIR125 | A | 1.42 | 1.15 | ± | 0.18 |
| | | | | | | | | B | 1.09 | | | |
| | | | | | | | | C | 0.99 | | | |
| | | | | | 5 | Whole rock | | D | 1.18 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kennedy Range 1 | | | 6606' | 6606' 9" | 3.5 | Whole rock | DIR126 | A | 4.63 | 4.76 | ± | 0.13 |
| | | | | | | | | B | 4.80 | | | |
| | | | | | | | | C | 4.87 | | | |
| GSWA Barrabiddy 1A | 781.70 | 781.95 | | | 3.5 | Whole rock | DIR127 | A | 2.44 | 2.50 | ± | 0.14 |
| | | | | | | | | B | 2.40 | | | |
| | | | | | | | | C | 2.66 | | | |
| GSWA Barrabiddy 1A | 773.90 | 774.10 | | | 3.5 | Whole rock | DIR128 | A | 3.22 | 3.37 | ± | 0.13 |
| | | | | | | | | B | 3.48 | | | |
| | | | | | | | | C | 3.42 | | | |
| GSWA Barrabiddy 1A | 759.55 | 759.70 | | | 3.5 | Whole rock | DIR129 | A | 2.14 | 1.80 | ± | 0.30 |
| | | | | | | | | B | 1.81 | | | |
| | | | | | | | | C | 1.55 | | | |
| GSWA Barrabiddy 1A | 669.35 | 669.55 | | | 3.5 | Whole rock | DIR130 | A | 2.52 | 2.49 | ± | 0.05 |
| | | | | | | | | B | 2.43 | | | |
| | | | | | | | | C | 2.51 | | | |
| GSWA Barrabiddy 1A | 616.90 | 617.10 | | | 3.5 | Whole rock | DIR131 | A | 1.75 | 1.93 | ± | 0.25 |
| | | | | | | | | B | 1.86 | | | |
| | | | | | | | | C | 2.22 | | | |
| GSWA Barrabiddy 1A | 617.65 | 617.90 | | | 5 | Hollow cell, whole rock | DIR132 | B | 0.64 | 0.64 | ± | 0.00 |
| | | | | | | | | C | 0.64 | | | |
| GSWA Barrabiddy 1A | 551.75 | 551.95 | | | 3.5 | Whole rock | DIR133 | A | 4.00 | 3.93 | ± | 0.08 |
| | | | | | | | | B | 3.85 | | | |
| | | | | | | | | C | 3.93 | | | |
| GSWA Barrabiddy 1A | 467.00 | 467.20 | | | 3.5 | Whole rock | DIR134 | A | 4.03 | 3.80 | ± | 0.29 |
| | | | | | | | | B | 3.92 | | | |
| | | | | | | | | C | 3.49 | | | |
| GSWA Barrabiddy 1A | 213.20 | 213.45 | | | 3.5 | Whole rock | DIR135 | A | 2.72 | 2.55 | ± | 0.18 |
| | | | | | | | | B | 2.59 | | | |
| | | | | | | | | C | 2.36 | | | |
| GSWA Barrabiddy 1A | 246.25 | 246.40 | | | 5 | Hollow cell, whole rock | DIR136 | B | 1.45 | 1.42 | ± | 0.04 |
| | | | | | | | | C | 1.40 | | | |
| Quail 1 | | | 8649' | 8649' 9" | 3.5 | Whole rock | DIR137 | B | 2.43 | 2.45 | ± | 0.03 |
| | | | | | | | | C | 2.47 | | | |
| Quail 1 | | | 7319' | 7319' 9" | 3.5 | Whole rock | DIR138 | A | 4.82 | 4.97 | ± | 0.24 |
| | | | | | | | | B | 4.87 | | | |
| | | | | | | | | C | 5.25 | | | |
| Onslow 1 | | | 3781' 3" | 3782' | 5 | Hollow cell, whole rock | DIR139 | A | 2.09 | 2.02 | ± | 0.09 |
| | | | | | | | | B | 1.96 | | | |
| | | | | | | | | C | 0.00 | | | |
| Onslow 1 | | | 4279' 9" | 4280' 6" | 3.5 | Whole rock | DIR140 | A | 3.06 | 2.91 | ± | 0.17 |
| | | | | | | | | B | 2.73 | | | |
| | | | | | | | | C | 2.96 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Onslow 1 | | | 5706' | 5706' 9" | 3.5 | Whole rock | DIR141 | A | 3.16 | 3.08 | ± | 0.09 |
| | | | | | | | | B | 2.98 | | | |
| | | | | | | | | C | 3.11 | | | |
| Onslow 1 | | | 6631' | 6631' 9" | 5 | Hollow cell, whole rock | DIR142 | A | 1.23 | 1.19 | ± | 0.08 |
| | | | | | | | | B | 1.25 | | | |
| | | | | | | | | C | 1.10 | | | |
| Learmonth 2 | | | 5375' | 5375' 9" | 3.5 | Whole rock | DIR143 | A | 3.27 | 3.42 | ± | 0.33 |
| | | | | | | | | B | 3.23 | | | |
| | | | | | | | | C | 3.83 | | | |
| Pluto 3 | 3056.70 | 3057.00 | | | 3.5 | Whole rock | DIR144 | A | 1.32 | 1.35 | ± | 0.09 |
| | | | | | | | | B | 1.45 | | | |
| | | | | | | | | C | 1.28 | | | |
| Pluto 3 | 3067.20 | 3067.50 | | | 3.5 | Whole rock | DIR145 | A | 2.38 | 1.84 | ± | 0.45 |
| | | | | | | | | B | 1.50 | | | |
| | | | | | | | | C | 1.78 | | | |
| Calliance 1 | 3776.00 | 3776.30 | | | 3.5 | Whole rock | DIR146 | A | 3.47 | 3.33 | ± | 0.15 |
| | | | | | | | | B | 3.18 | | | |
| | | | | | | | | C | 3.35 | | | |
| Brecknock 2 | 3786.80 | 3787.00 | | | 3.5 | Whole rock | DIR147 | A | 4.47 | 4.51 | ± | 0.10 |
| | | | | | | | | B | 4.43 | | | |
| | | | | | | | | C | 4.62 | | | |
| Calliance 1 | 3797.20 | 3797.40 | | | 3.5 | Whole rock | DIR148 | A | 2.72 | 2.82 | ± | 0.12 |
| | | | | | | | | B | 2.80 | | | |
| | | | | | | | | C | 2.95 | | | |
| Brecknock 2 | 3825.70 | 3825.90 | | | 3.5 | Whole rock | DIR149 | A | 2.48 | 2.29 | ± | 0.17 |
| | | | | | | | | B | 2.24 | | | |
| | | | | | | | | C | 2.16 | | | |
| Yowalga 2 | | | 2796' | 2796' 9" | 3.5 | Whole rock | DIR150 | A | 2.37 | 2.56 | ± | 0.18 |
| | | | | | | | | B | 2.61 | | | |
| | | | | | | | | C | 2.71 | | | |
| Yowalga 2 | | | 3242' | 3242' 9" | 5 | Hollow cell, whole rock | DIR151 | A | 2.77 | 2.93 | ± | 0.24 |
| | | | | | | | | B | 3.11 | | | |
| Bonaparte 1A | | | 576' 4"/ 578' 4" | 576' 8"/ 578' 8" | 3.5 | Whole rock | DIR152 | A | 3.14 | 2.94 | ± | 0.32 |
| | | | | | | | | B | 3.16 | | | |
| | | | | | | | | C | 2.59 | | | |
| Bonaparte 1A | | | 689' 8" | 690' | 3.5 | Whole rock | DIR153 | A | 2.20 | 2.19 | ± | 0.02 |
| | | | | | | | | B | 2.17 | | | |
| | | | | | | | | C | 2.20 | | | |
| Bonaparte 2 | | | 3948' 4"/ 3940' 4" | 3948' 8"/ 3940' 8" | 3.5 | Whole rock | DIR154 | A | 4.24 | 3.92 | ± | 0.58 |
| | | | | | | | | B | 4.39 | | | |
| | | | | | | | | C | 3.32 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bonaparte 1A | | | 9267' 4"/ 9263' 4" | 9267' 8"/ 9263' 8" | 3.5 | Whole rock | DIR155 | A | 1.77 | 1.73 | ± | 0.06 |
| | | | | | | | | B | 1.76 | | | |
| | | | | | | | | C | 1.66 | | | |
| Bonaparte 1A | | | 10476' 4" | 10476' 8" | 3.5 | Whole rock | DIR156 | A | 5.67 | 5.09 | ± | 0.51 |
| | | | | | | | | B | 4.67 | | | |
| | | | | | | | | C | 5.04 | | | |
| Laminaria East 1 | 3249.70 | 3249.90 | | | 3.5 | Whole rock | DIR157 | A | 1.26 | 1.24 | ± | 0.03 |
| | | | | | | | | B | 1.21 | | | |
| GSWA Barrabiddy 1A | 66.00 | 66.30 | | | 15 | Hollow cell, matrix | DIR158 | A | 1.21 | 1.19 | ± | 0.03 |
| | | | | | | | | B | 1.21 | | | |
| | | | | | | | | C | 1.16 | | | |
| GSWA Barrabiddy 1A | 127.75 | 127.95 | | | 3.5 | Whole rock | DIR159 | A | 1.40 | 1.31 | ± | 0.10 |
| | | | | | | | | B | 1.35 | | | |
| | | | | | | | | C | 1.20 | | | |
| GSWA Barrabiddy 1A | 157.30 | 157.45 | | | 5 | Hollow cell, whole rock | DIR160 | A | 1.81 | 1.79 | ± | 0.05 |
| | | | | | | | | B | 1.74 | | | |
| | | | | | | | | C | 1.82 | | | |
| Turtle 1 | 2488.20 | 2488.50 | | | 3.5 | Whole rock | DIR161 | A | 4.20 | 4.11 | ± | 0.08 |
| | | | | | | | | B | 4.05 | | | |
| | | | | | | | | C | 4.08 | | | |
| Turtle 1 | 929.00 | 929.30 | | | 3.5 | Whole rock | DIR162 | A | 2.59 | 2.60 | ± | 0.05 |
| | | | | | | | | B | 2.65 | | | |
| | | | | | | | | C | 2.56 | | | |
| Turtle 1 | 932.45 | 932.70 | | | 5 | Hollow cell, whole rock | DIR163 | A | 2.34 | 2.38 | ± | 0.05 |
| | | | | | | | | B | 2.36 | | | |
| | | | | | | | | C | 2.44 | | | |
| Turtle 1 | 1441.65 | 1441.85 | | | 3.5 | Whole rock | DIR164 | A | 2.14 | 2.29 | ± | 0.31 |
| | | | | | | | | B | 2.67 | | | |
| | | | | | | | | C | 2.13 | | | |
| Turtle 1 | 1599.65 | 1599.95 | | | 3.5 | Whole rock | DIR165 | A | 3.17 | 3.19 | ± | 0.05 |
| | | | | | | | | B | 3.24 | | | |
| | | | | | | | | C | 3.15 | | | |
| Turtle 1 | 1601.50 | 1601.75 | | | 3.5 | Whole rock | DIR166 | A | 2.32 | 2.35 | ± | 0.09 |
| | | | | | | | | B | 2.45 | | | |
| | | | | | | | | C | 2.28 | | | |
| Turtle 1 | 1612.00 | 1612.30 | | | 3.5 | Whole rock | DIR167 | A | 2.71 | 2.87 | ± | 0.39 |
| | | | | | | | | B | 2.66 | | | |
| | | | | | | | | C | 3.35 | | | |
| GSWA Empress 1A | 165.90 | 166.10 | | | 5 | Hollow cell, whole rock | DIR168 | A | 2.71 | 2.56 | ± | 0.14 |
| | | | | | | | | B | 2.53 | | | |
| | | | | | | | | C | 2.44 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GSWA Empress 1A | 127.05 | 127.20 | | | 5 | Hollow cell, whole rock | DIR169 | A | 2.28 | 2.19 | ± | 0.10 |
| | | | | | | | | B | 2.21 | | | |
| | | | | | | | | C | 2.09 | | | |
| GSWA Empress 1A | 116.15 | 116.40 | | | 3.5 | Whole rock | DIR170 | A | 3.32 | 3.27 | ± | 0.07 |
| | | | | | | | | B | 3.22 | | | |
| GSWA Empress 1A | 294.25 | 294.60 | | | 5 | Hollow cell, whole rock | DIR171 | A | 2.49 | 2.44 | ± | 0.05 |
| | | | | | | | | B | 2.38 | | | |
| | | | | | | | | C | 2.44 | | | |
| GSWA Empress 1A | 106.70 | 107.00 | | | 5 | Hollow cell, whole rock | DIR172 | A | 2.47 | 2.49 | ± | 0.05 |
| | | | | | | | | B | 2.44 | | | |
| | | | | | | | | C | 2.54 | | | |
| GSWA Empress 1A | 284.70 | 284.90 | | | 3.5 | Whole rock | DIR173 | A | 1.55 | 1.57 | ± | 0.02 |
| | | | | | | | | B | 1.58 | | | |
| | | | | | | | | C | 1.58 | | | |
| GSWA Empress 1A | 367.80 | 368.00 | | | 5 | Hollow cell, whole rock | DIR174 | A | 2.21 | 2.26 | ± | 0.07 |
| | | | | | | | | B | 2.31 | | | |
| GSWA Empress 1A | 351.80 | 352.00 | | | 5 | Hollow cell, whole rock | DIR175 | A | 3.07 | 3.05 | ± | 0.05 |
| | | | | | | | | B | 2.99 | | | |
| | | | | | | | | C | 3.09 | | | |
| GSWA Empress 1A | 431.50 | 431.70 | | | 15 | Hollow cell, matrix | DIR176 | A | 1.61 | 1.55 | ± | 0.21 |
| | | | | | | | | B | 1.75 | | | |
| | | | | | | | | C | 1.34 | | | |
| GSWA Empress 1A | 504.65 | 504.85 | | | 3.5 | Whole rock | DIR177 | A | 4.68 | 4.61 | ± | 0.23 |
| | | | | | | | | B | 4.80 | | | |
| | | | | | | | | C | 4.36 | | | |
| GSWA Empress 1A | 603.80 | 604.00 | | | 15 | Hollow cell, matrix | DIR178 | A | 1.43 | 1.43 | ± | 0.16 |
| | | | | | | | | B | 1.29 | | | |
| | | | | | | | | C | 1.60 | | | |
| GSWA Empress 1A | 568.30 | 568.50 | | | 3.5 | Whole rock | DIR179 | A | 3.04 | 2.96 | ± | 0.12 |
| | | | | | | | | B | 3.03 | | | |
| | | | | | | | | C | 2.83 | | | |
| GSWA Empress 1A | 651.40 | 651.70 | | | 3.5 | Whole rock | DIR180 | A | 3.87 | 4.02 | ± | 0.25 |
| | | | | | | | | B | 4.32 | | | |
| | | | | | | | | C | 3.90 | | | |
| GSWA Empress 1A | 743.50 | 743.80 | | | 3.5 | Whole rock | DIR181 | A | 2.13 | 3.02 | ± | 0.99 |
| | | | | | | | | B | 3.71 | | | |
| | | | | | | | | C | 3.95 | | | |
| GSWA Empress 1A | 805.90 | 806.10 | | | 3.5 | Whole rock | DIR182 | A | 2.78 | 2.41 | ± | 0.34 |
| | | | | | | | | B | 2.10 | | | |
| | | | | | | | | C | 2.44 | | | |
| GSWA Empress 1A | 931.00 | 931.30 | | | 3.5 | Whole rock | DIR183 | A | 3.97 | 4.18 | ± | 0.19 |
| | | | | | | | | B | 4.34 | | | |
| | | | | | | | | C | 4.25 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GSWA Empress 1A | 1122.10 | 1122.40 | | | 3.5 | Whole rock | DIR184 | A | 4.34 | 4.24 | ± | 0.25 |
| | | | | | | | | B | 4.44 | | | |
| | | | | | | | | C | 3.97 | | | |
| GSWA Empress 1A | 1091.10 | 1091.30 | | | 3.5 | Whole rock | DIR185 | A | 1.78 | 1.78 | ± | 0.36 |
| | | | | | | | | B | 2.22 | | | |
| | | | | | | | | C | 1.50 | | | |
| GSWA Empress 1A | 1075.90 | 1076.20 | | | 3.5 | Whole rock | DIR186 | A | 5.65 | 5.54 | ± | 0.11 |
| | | | | | | | | B | 5.53 | | | |
| | | | | | | | | C | 5.43 | | | |
| GSWA Empress 1A | 1223.30 | 1223.55 | | | 3.5 | Whole rock | DIR187 | A | 2.14 | 2.18 | ± | 0.06 |
| | | | | | | | | B | 2.16 | | | |
| | | | | | | | | C | 2.25 | | | |
| GSWA Empress 1A | 1309.65 | 1309.80 | | | 3.5 | Whole rock | DIR188 | A | 5.65 | 5.25 | ± | 0.37 |
| | | | | | | | | B | 5.25 | | | |
| | | | | | | | | C | 4.92 | | | |
| GSWA Empress 1A | 1409.40 | 1409.55 | | | 3.5 | Whole rock | DIR189 | A | 2.60 | 2.68 | ± | 0.12 |
| | | | | | | | | B | 2.82 | | | |
| | | | | | | | | C | 2.63 | | | |
| GSWA Empress 1A | 1403.75 | 1403.95 | | | 5 | Hollow cell, whole rock | DIR190 | A | 2.13 | 2.09 | ± | 0.06 |
| | | | | | | | | C | 2.04 | | | |
| GSWA Empress 1A | 1531.70 | 1531.90 | | | 3.5 | Whole rock | DIR191 | A | 1.65 | 1.61 | ± | 0.04 |
| | | | | | | | | B | 1.57 | | | |
| | | | | | | | | C | 1.62 | | | |
| GSWA Empress 1A | 1603.60 | 1603.80 | | | 3.5 | Whole rock | DIR192 | A | 2.34 | 2.30 | ± | 0.05 |
| | | | | | | | | B | 2.25 | | | |
| | | | | | | | | C | 2.30 | | | |
| GSWA Empress 1A | 1558.90 | 1559.20 | | | 3.5 | Whole rock | DIR193 | A | 2.09 | 2.05 | ± | 0.05 |
| | | | | | | | | B | 2.08 | | | |
| | | | | | | | | C | 1.99 | | | |
| Boondawari 1 | 302.20 | 302.40 | | | 3.5 | Whole rock | DIR194 | A | 4.37 | 4.45 | ± | 0.09 |
| | | | | | | | | B | 4.55 | | | |
| | | | | | | | | C | 4.44 | | | |
| Boondawari 1 | 613.30 | 613.50 | | | 3.5 | Whole rock | DIR195 | A | 1.47 | 1.43 | ± | 0.04 |
| | | | | | | | | B | 1.40 | | | |
| | | | | | | | | C | 1.43 | | | |
| Boondawari 1 | 612.35 | 612.60 | | | 3.5 | Whole rock | DIR196 | A | 4.80 | 4.81 | ± | 0.09 |
| | | | | | | | | B | 4.90 | | | |
| | | | | | | | | C | 4.73 | | | |
| Boondawari 1 | 1365.40 | 1365.60 | | | 3.5 | Whole rock | DIR197 | A | 2.18 | 2.25 | ± | 0.07 |
| | | | | | | | | B | 2.32 | | | |
| | | | | | | | | C | 2.26 | | | |
| Boondawari 1 | 834.60 | 834.80 | | | 3.5 | Whole rock | DIR198 | A | 4.19 | 4.45 | ± | 0.30 |
| | | | | | | | | B | 4.42 | | | |
| | | | | | | | | C | 4.79 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boondawari 1 | 349.60 | 349.80 | | | 3.5 | Whole rock | DIR199 | A | 2.22 | 2.17 | ± | 0.08 |
| | | | | | | | | B | 2.08 | | | |
| | | | | | | | | C | 2.23 | | | |
| BMR Browne 1 | | | 30' 11" | 31' 7" | 3.5 | Whole rock | DIR200 | A | 1.34 | 1.33 | ± | 0.01 |
| | | | | | | | | B | 1.31 | | | |
| | | | | | | | | C | 1.33 | | | |
| BMR Browne 1 | | | 325' | 325' 6" | 5 | Hollow cell, whole rock | DIR201 | A | 1.32 | 1.30 | ± | 0.04 |
| | | | | | | | | B | 1.25 | | | |
| | | | | | | | | C | 1.34 | | | |
| BMR Browne 1 | | | 192' 1" | 192' 7" | 5 | Hollow cell, whole rock | DIR202 | A | 1.27 | 1.25 | ± | 0.03 |
| | | | | | | | | B | 1.23 | | | |
| BMR Neale 1A-1B | | | 369' 11" | 369' 11" | 3.5 | Whole rock | DIR203 | A | 2.52 | 2.60 | ± | 0.08 |
| | | | | | | | | B | 2.68 | | | |
| | | | | | | | | C | 2.61 | | | |
| BMR Neale 1A-1B | | | 327' | 327' 7" | 3.5 | Whole rock | DIR204 | B | 1.73 | 2.16 | ± | 0.81 |
| | | | | | | | | D | 2.87 | | | |
| BMR Neale 1A-1B | | | 308' | 308' 9" | 5 | Hollow cell, whole rock | DIR205 | A | 1.59 | 1.59 | ± | 0.05 |
| | | | | | | | | B | 1.55 | | | |
| | | | | | | | | C | 1.64 | | | |
| BMR Throssell 1 | | | 200' | 200' 10" | 3.5 | Whole rock | DIR206 | Specimen not measured | | | | |
| BMR Glenburgh 9 | | | 192' | 192' 6" | 3.5 | Whole rock | DIR207 | A | 1.50 | 1.53 | ± | 0.05 |
| | | | | | | | | B | 1.58 | | | |
| | | | | | | | | C | 1.50 | | | |

# 4. Discussion and Conclusions

### *4.1 Bonaparte Basin*

The range of thermal conductivity values from the Bonaparte basin is from 1.24–5.09 W/mK, shown by specimens DIR157 and DIR156 respectively, which is a variability of up to a 79% from mean basin conductivity of 2.84 W/mK. The standard deviation between all 13 samples representing the Bonaparte basin is approximately 1.04σ.

### *4.2 Browse Basin*

The range of thermal conductivity values from the Browse basin is from 2.29–4.51 W/mK, shown by specimens DIR149 and DIR147 respectively, which is a variability of up to a 39% from the mean basin conductivity of 3.24 W/mK. The standard deviation between all four samples representing the Browse basin is approximately 0.82σ.

### *4.3 Carnarvon Basin*

The range of thermal conductivity values for the Carnarvon basin is from 0.64–4.97 W/mK, shown by specimens DIR138 and DIR132 respectively, which is a variability of up to a 97% from the mean basin conductivity of 2.52 W/mK. The standard deviation between all 61 samples representing the Carnarvon basin is approximately 0.89σ.

### *4.4 Officer Basin*

The range of thermal conductivity values for the Officer basin is from 1.25–5.54 W/mK, shown by specimens DIR202 and DIR186 respectively, which is a variability of up to 103% from the mean basin conductivity of 2.73 W/mK. The standard deviation between all 40 samples representing the Officer basin is approximately 1.17σ. Thermal conductivity of specimen DIR206 was not measured due to poor sample quality.

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[5], 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[2], typically decreasing at a rate of around 0.16% per °C. This should be kept in mind when developing models of in situ thermal conductivity.

[5] **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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