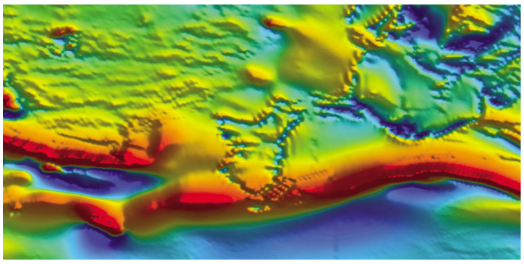
Government of Western Australia
Department of Mines and Petroleum

RECORD 2010/24

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

by
Hot Dry Rocks Pty Ltd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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 (Bonaparte 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 Western Australian portion of the onshore Bonaparte Basin. Ten wells were assessed in detail for heat flow modelling. Of these 10 wells, nine had sufficient data to enable the modelling of heat flow.

The principle findings of this report are:-

- The Bonaparte Basin covers an area of approximately 270,000 km^2 of which just over 20,000 km^2 lies onshore. The limited number of wells and geophysical datasets hinders a comprehensive evaluation of the geothermal prospectivity.
- The Perth Core Library only holds limited core available for analysis from the onshore Bonaparte Basin. HDR was only able to collect 13 specimens for rock thermal conductivity measurements. The measured rock thermal conductivities for the specimens ranged from 1.24–5.09 W/mK. These data were crucial for the development of 1D heat flow models.
- Apparent surface heat flow in the onshore Bonaparte Basin ranges from 60–103 mW/m^2 with a median value of 76 mW/m^2. This value is higher than the Australian median value of 64.5 mW/m^2 (from the global heat flow database).
- The Milligans Formation is identified as a crucial formation for the development of the 1D heat flow models. HDR recommends further analyses be performed on the limited core specimens to better constrain the thermal conductivity of the Milligans Formation.
- The preliminary heat flow results published in this report could be further enhanced by acquiring additional data from existing water and minerals bores.

HDR suggests a concerted effort to locate existing bores. Furthermore, DMP should consider collecting temperature data from minerals and petroleum companies that are planning new bores.

- HDR recommends that the heat generation potential of basement rocks be further investigated by the DMP.

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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Table of Contents

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 Western Australian portion of the onshore Bonaparte Basin. An initial 10 wells were highlighted by DMP for this study (Attachment A). HDR generated a single heat flow model incorporating data from Waggon Creek-1 and Waggon Creek-1A, so this report relates to nine individual well models.

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 onshore Bonaparte Basin.

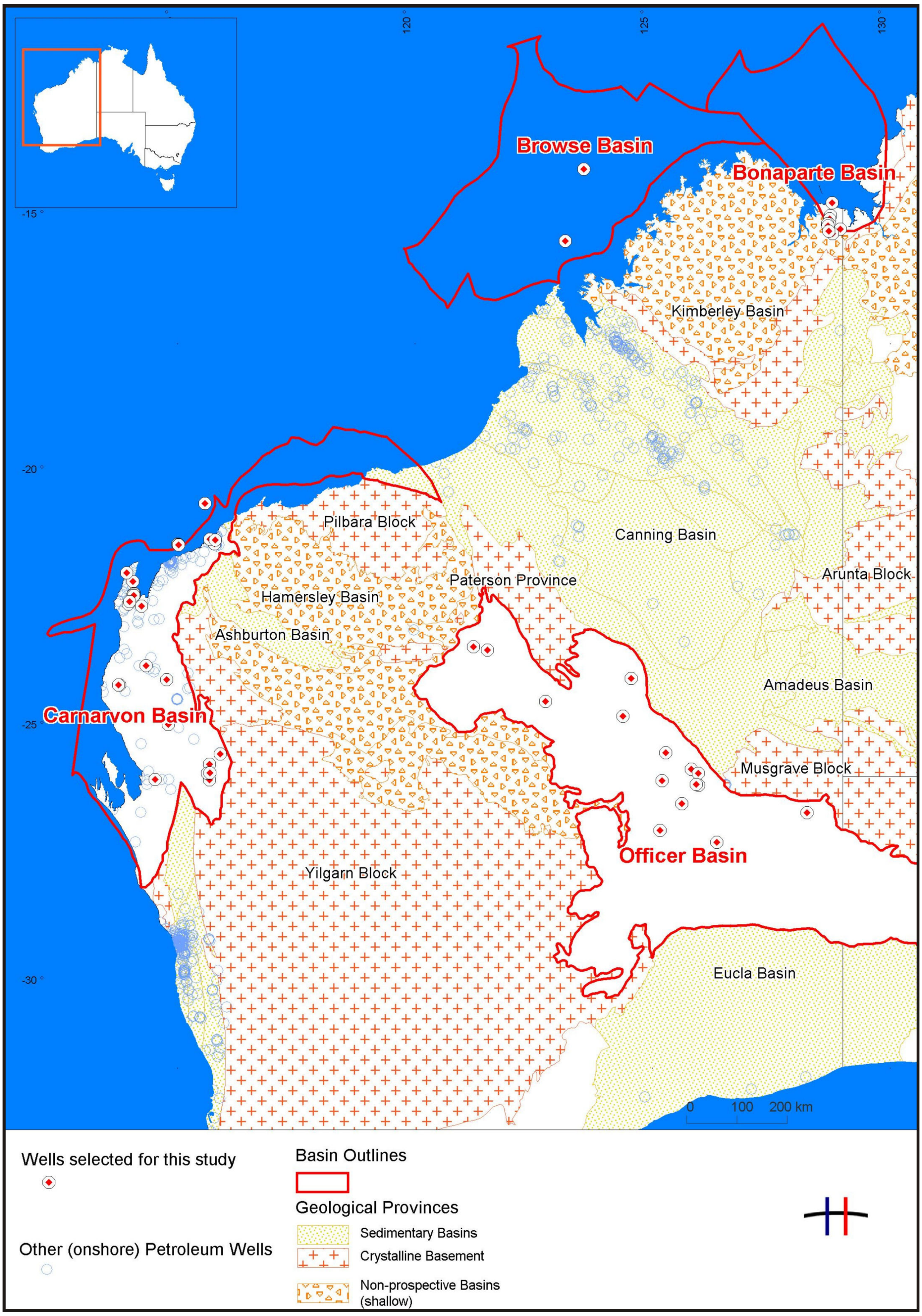

Figure 1: Location of the Bonaparte, Browse, Carnarvon and Officer basins, Western Australia (individual basin polygons modified from Geoscience Australia databases).

2. Bonaparte Basin Geological Setting

The Bonaparte 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. The basin straddles the Western Australia and Northern Territory border, and covers a total area of approximately 270,000 km^2 of which just over 20,000 km^2 lies onshore—the focus of this geothermal assessment. The offshore Bonaparte Basin is the site of numerous petroleum discoveries and several fields are currently producing.

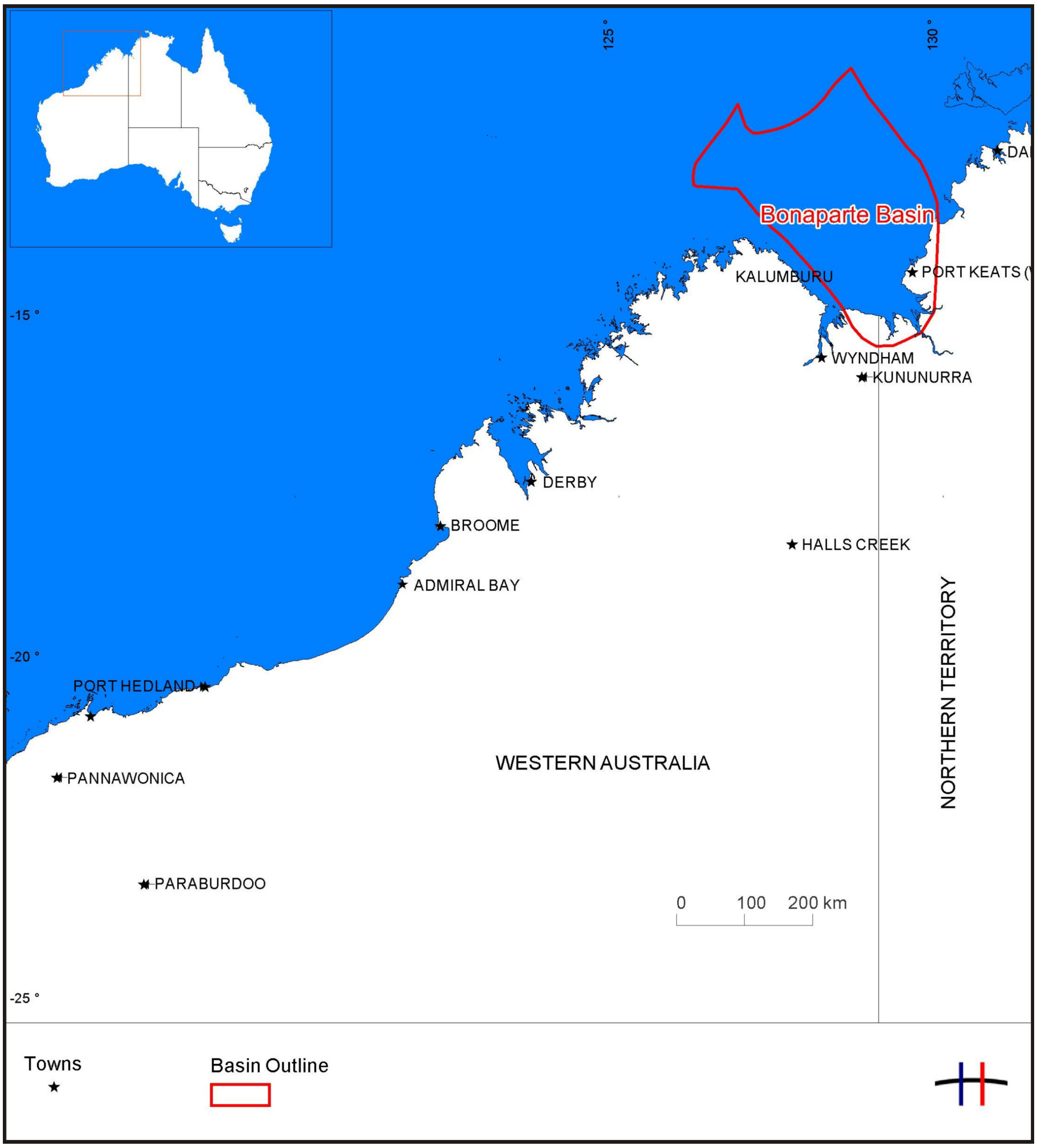

Figure 2: Location of the Bonaparte Basin (basin polygon from Geoscience Australia database).

The Bonaparte Basin is structurally complex, comprising a number of Palaeozoic to Mesozoic graben and platform areas, and contains up to 15 km of sedimentary fill. The stratigraphy of the onshore Bonaparte Basin is shown in Figure 3. A more detailed discussion of the structural evolution and stratigraphic succession can be found in Beere & Mory (1986), Mory & Beere (1988); Mory (1991); and Cadman & Temple (2003).

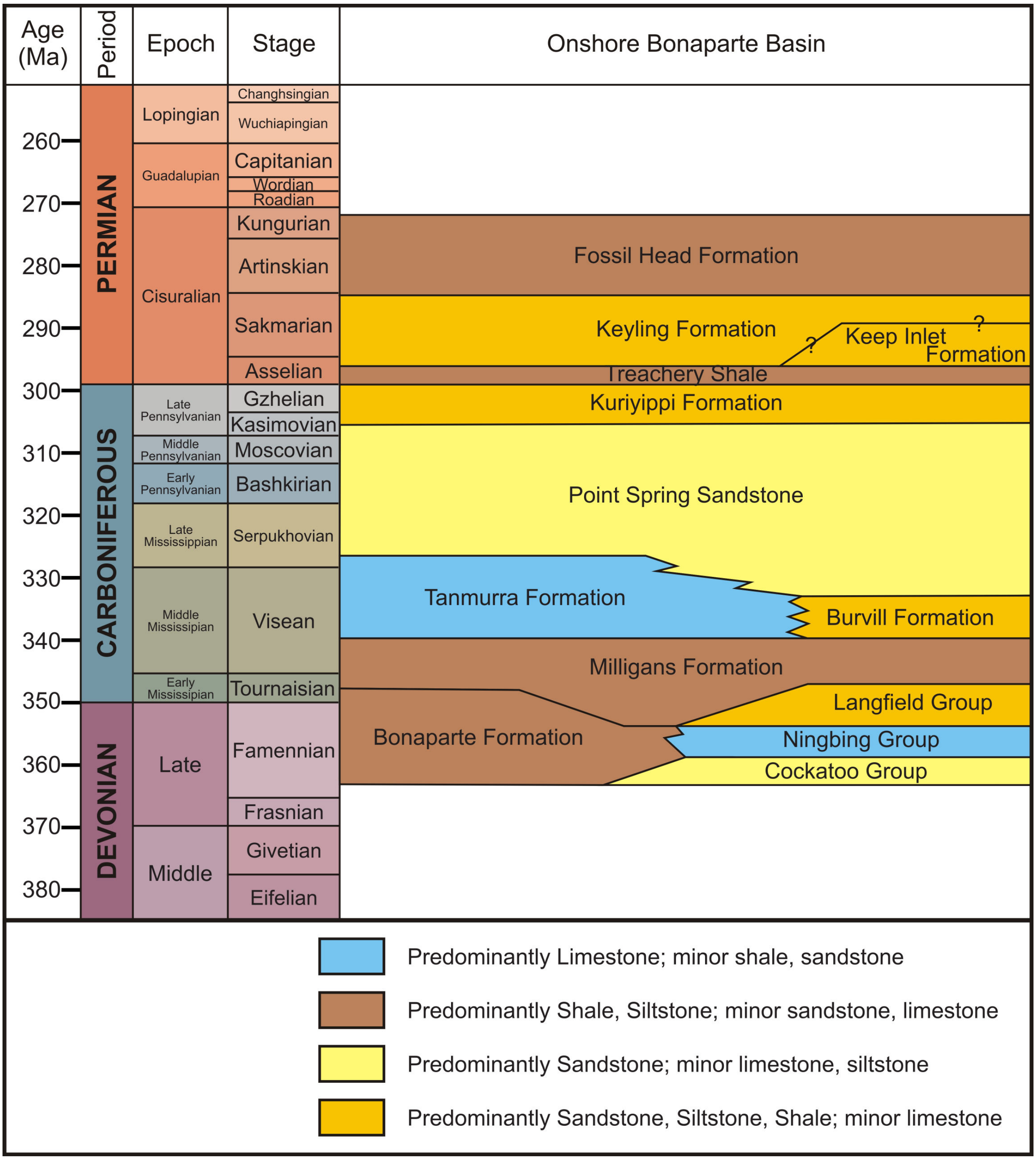

Figure 3: Stratigraphy of the onshore Bonaparte Basin (modified from Cadman & Temple, 2003).

3. Basement Investigations

This section provides information for the following topics:-

For the nine wells to be assessed:-

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

3.1. Basement depth

All recorded actual basement intercepts in both the Western Australian and the Northern Territory portions of the Bonaparte Basin (Attachment B) were assessed in conjunction with the OZ SEEBASEv2 database (FrOG Tech, 2007) to predict depth-to-basement[1] for the nine wells modelled for this report. The actual basement intercepts recorded in wells were given greater weighting over the OZ SEEBASEv2 dataset. Results are presented in Attachment C.

3.2. Basement lithology.

Predictions of basement lithology (Attachment C) are shown on Figure 4. Most were derived from basement lithologies intersected in nearby wells, with the assumption that a similar lithology may be intersected within a 10 km radius (being the approximate size of a small pluton). Others were derived from the continuation of geophysical signatures (gravity and magnetics) from areas of known basement composition. The exact nature of the basement of the Bonaparte Basin remains poorly constrained due to the small number of current basement intercepts.

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[1] Rounded to the nearest 250 m.

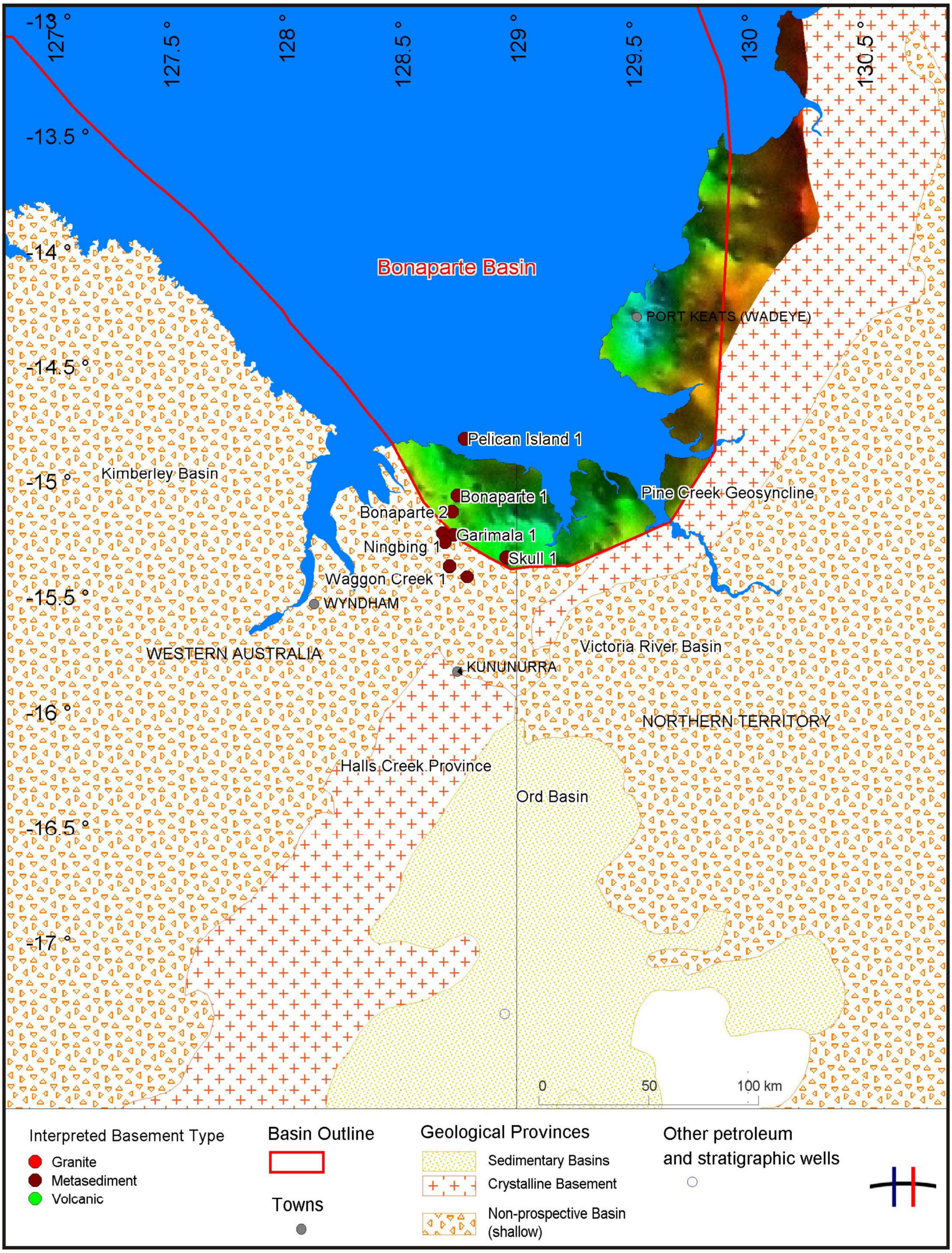

Figure 4: Predicted basement lithology in the onshore Bonaparte Basin beneath petroleum wells listed in Attachment A. A gravity image of the basin provides the backdrop.

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 nine wells in the onshore Bonaparte 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 nine wells in the onshore Bonaparte 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 onshore Bonaparte Basin (Wyndham 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. Temperature data issues

HDR checked the well temperature compilation provided by the DMP against primary data in well completion reports and noticed whilst bottom hole temperatures (BHT) were recorded, other sources of temperature data such as drill stem tests (DST) and formation tests were not always recorded. These data are invaluable for constraining the temperature regime in a well. HDR found it necessary to check each well and compile an internal temperature database to ensure all temperature data had been accurately extracted and recorded.

4.6. 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 13 representative samples from lithologies of the Bonaparte 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.

4.7. Rock thermal conductivity estimation

Rock thermal conductivity is highly dependent upon lithology. In the absence of thermal conductivity measurements, 'lithology mixing' provides a reasonable basis for estimating formational conductivity for the purpose of basin-wide thermal modelling, within the constraints described within this report. 'Lithology mixing' derives the weighted harmonic mean of the conductivities of the same or similar lithologies as the components of the particular formation under investigation. This process is described in Beardsmore and Cull (2001).

The 13 measurements of thermal conductivity in this study included a number of measurements on 'pure' lithological samples such as 'shale', 'sandstone', etc.

Gamma ray logs from nearby wells were examined to interpret the relative proportions of sand and shale over specific formation intervals. As a high gamma response might also be expected from radioactive minerals in sandstone, the interpretations were modified using the lithology log where appropriate. The thermal conductivities of these intervals were then estimated using 'lithology mixing'. A summary of the calculation inputs is provided in Attachment E.

Thermal conductivity values for each onshore Bonaparte Basin formation, as derived using the methods described in sections 4.6 and 4.7 and used in the 1D heat flow models, are shown in Table 1.

Table 1: Thermal conductivities by formation for the onshore Bonaparte Basin, as used for 1D heat flow modelling in this report. See Appendix 2 for more details.

Formation	Conductivity (W/mK)	Uncertainty ± (W/mK)
Alluvium	1.42	0.14
Fossil Head Formation	2.29	0.46
Keyling Formation	2.48	0.05
Keep Inlet Formation	2.12	0.42
Treachery Shale	2.29	0.31
Kuriyippi Formation	2.76	0.17
Point Spring Sandstone	2.94	0.32
Tanmurra Formation	2.19	0.02
Burvill Formation	3.28	0.66
Milligans Formation	2.20	0.50
Bonaparte Formation	4.11	0.08
Langfield Group	2.38	0.48
Burt Range Formation	1.73	0.06
Ningbing Group	3.23	0.65
Cockatoo Group	5.09	0.51
?Palaeozoic Halite	5.25	1.05

The Milligans Formation specimen HDR collected from the Perth Core Store yielded a thermal conductivity value of 3.92 ± 0.58 W/mK and is a *heterolithic fine-grained light grey sst and dark grey slt*. However, the Milligans Formation is described by Mory and Beere (1988) as *shale and minor siltstone*; and the type section *grey to* *black silty shale which is locally calcareous, gypsiferous or pyritic*. The measured thermal conductivity value is high for the formation description so HDR assumed that the specimen was collected from a sandier section of the formation. Unfortunately, the formation has only limited core available for testing. HDR judged that 2.20 ± 0.58 W/mK was a more appropriate conductivity value.

- **HDR recommends further core specimens from the Milligans Formation be tested for thermal conductivity**

The limited number of specimens measured reflects the limited core available for testing. It was therefore necessary for HDR to allocate thermal conductivity values to some formations based on similar aged lithologies in the adjacent Carnarvon and Canning basins, as well as the Officer Basin. As rock thermal conductivity is highly dependent upon lithology, an uncertainty of 20% was assigned to each estimate to reflect this.

4.8. Predicting lithologies at depth

1D heat flow models for temperature prediction at depth require detailed lithological data, and associated rock thermal conductivities, for all formations down to the modelled depth. HDR utilised the DMP formation top database to constrain lithologies within the drilled portion of the heat flow models.

The DMP formation top database contained a number of inconsistencies when cross-referenced with the well completion reports.

The lithologies and thicknesses of deeper formations were estimated using other available data. HDR utilised existing deep wells to estimate the thickness of individual formations as a ratio of the entire stratigraphic column. OZ SEEBASEv2 depth-to-basement estimates for all wells (FrOG Tech, 2007; Attachment C) were used to constrain the overall thickness of the sedimentary section, to which the formation-specific ratios were applied.

In order to make this methodology as robust as possible, wells that reached total depth within the sedimentary sequence were tied to the nearest deep well that intersected basement. This process assumed that the units within the sedimentary pile would continue laterally between the wells in a relatively constant ratio. Whilst simplistic, this methodology provides one of the few mechanisms to estimate the likely thickness of deep units for which there is a paucity of data.

In summary, whilst there remains significant uncertainty in the estimated thickness and distribution of non-intersected formations within the onshore Bonaparte Basin, HDR used all available data to make reasonable assessments on a regional scale to minimise the uncertainty.

4.9. 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 onshore Bonaparte 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 onshore Bonaparte Basin, data from the Halls Creek Region were utilised as proxies, assuming that similar rocks may partly comprise the basement of the onshore Bonaparte 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 onshore Bonaparte 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 onshore Bonaparte Basin. The data suggest that the heat generating potential of metasedimentary rocks around the onshore Bonaparte Basin is not elevated.

- **HDR recommends that the heat generation potential of basement rocks be further investigated by the DMP**

Table 2: Summary of heat generation estimates for basement around the onshore Bonaparte Basin

Lithology	Number of samples	Assumed density (g/cm3)	Heat generation (µW/m3) Range	Heat generation (µW/m3) Median
Metasedimentary	16	2.48	0.51-3.68	1.83

5. Heat flow modelling

5.1. Estimated heat flow

HDR constructed 1D conductive heat flow models (Figure 5) for the nine wells in the onshore Bonaparte 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 each of the nine wells. Heat flow was adjusted until the predicted temperature profile best fit the reported temperature datasets.

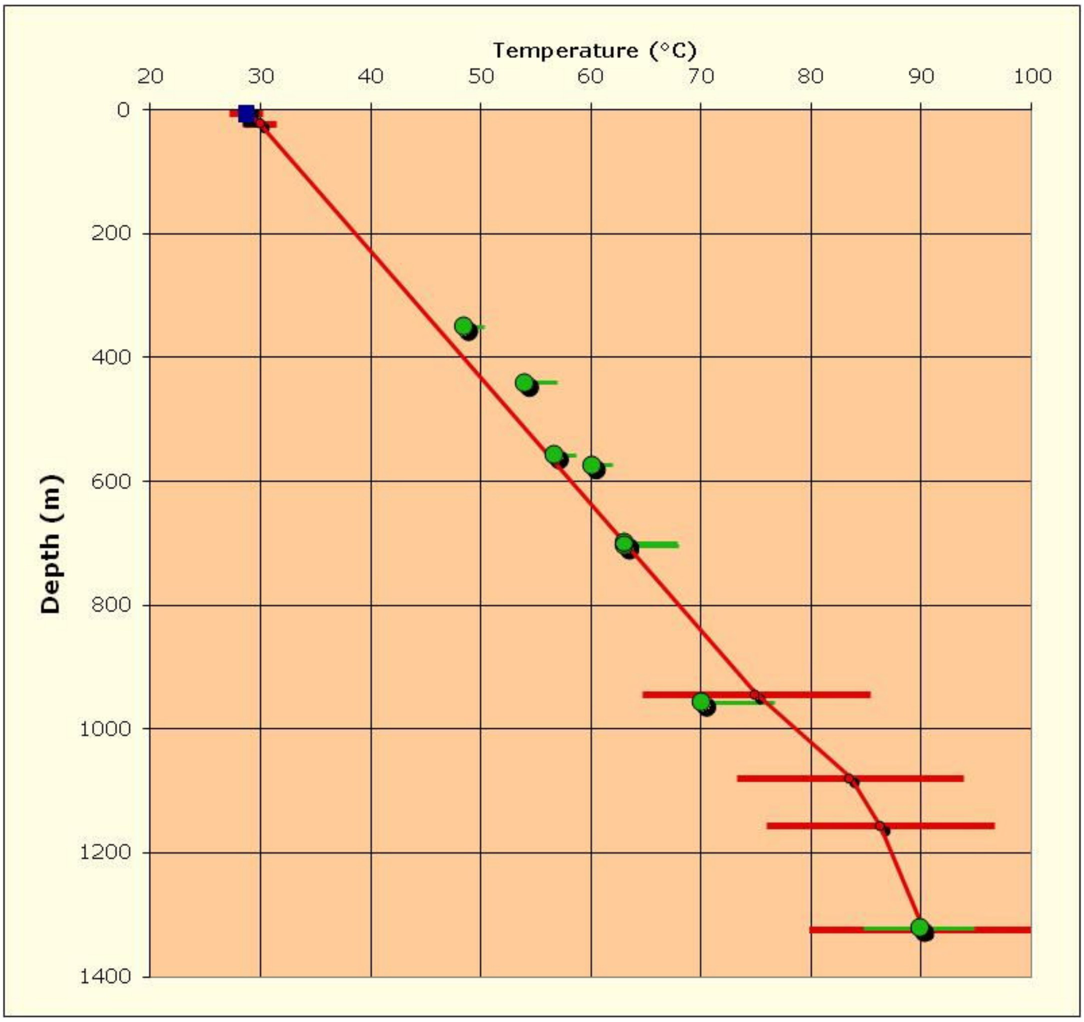

Figure 5: 1D heat flow model for the Waggon Creek-1A petroleum well. The green circles represent individual temperature data; the green lines represent the degree of uncertainty; the red line is the predicted temperature profile for a heat flow of 103 ± 17.2 mW/m^2

Modelled heat flow for the onshore Bonaparte Basin ranges from 60 to 103 mW/m^2, with a median value of 76 mW/m^2. The distribution of heat flow away from well control points remains relatively unconstrained.

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. For example, a well constrained Horner corrected or DST temperature was assigned a narrow uncertainty range centred on the corrected value. Uncorrected BHT values, however, were assigned a very low or zero uncertainty on the 'negative' side and a much larger uncertainty on the 'positive' side to reflect the fact that these data are very likely to understate 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 all 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). Of the nine wells modelled in this study, only two were ascribed a reliability ranking of 1 or 2.

Table 3: Reliability ranking scheme for the nine wells modelled in the onshore Bonaparte 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 and Recommendations

Data from the nine wells modelled in this study suggest that the onshore Bonaparte Basin has a median apparent heat flow value of 76 mW/m^2. This value is higher than the Australian median value of 64.5 mW/m^2 (from the global heat flow database) and the median values previously estimated by HDR for the Canning Basin (68 mW/m^2) and the Perth Basin (76.5 mW/m^2) [Driscoll et al. (2009) and HDRPL (2008) respectively].

The Perth Core Library only holds limited core available for analysis from the onshore Bonaparte Basin. The measured rock thermal conductivities for 13 core specimens ranged from 1.24–5.09 W/mK and these data were crucial for the development of 1D heat flow models.

HDR makes the following specific recommendations with regards to future studies:

- DMP should obtain new data via Precision Temperature Logging (PTL) of existing petroleum wells, minerals bores and water bores. This will provide crucial data to delineate heat flow in other parts of the onshore Bonaparte Basin.
- DMP should contact all minerals and petroleum companies that have leases in the onshore Bonaparte Basin. DMP should request that temperature, lithology and stress data be collected as part of any work program when new wells and bores are drilled.
- Further analysis should be performed on the limited core specimens to better constrain the thermal conductivity of the Milligans Formation.
- DMP should further investigate the heat generation potential of basement rocks.

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Attachment A: Wells in the onshore Bonaparte Basin that form this study.

Well Name	Sub-basin	Well ID	Well Status	Deviated well?	Total Depth (mTVD)	Age at Total Depth	Lithostratigraphic Unit	Datum	Latitude (°)	Longitude (°)
Bonaparte 1	Petrel Sub-basin	W000001	Petroleum	no	3209.5	Late Devonian	Cockatoo Group	GDA94	-15.015230	128.744298
Bonaparte 2	Carlton Shelf	W000078	Petroleum	no	2136.0	Late Devonian	Langfield Group (Burt Range Formation)	GDA94	-15.083841	128.722353
Garimala 1	Carlton Shelf	W001584	Petroleum	no	2553.0	Late Devonian	Langfield Group (Bonaparte Formation)	GDA94	-15.186481	128.727571
Ningbing 1	Carlton Shelf	W001185	Petroleum	no	1269.0	Late Devonian	Cockatoo Group	GDA94	-15.180576	128.681827
Ningbing 2	Carlton Shelf	W002061	Petroleum	no	1336.0	Late Devonian	Ningbing Group	GDA94	-15.218631	128.690441
Pelican Island 1	Petrel Sub-basin	W000826	Petroleum	no	1981.0	Middle Devonian	?Palaeozoic Halite	GDA94	-14.770507	128.775411
Skull 1	Burt Range Shelf	W001358	Petroleum	no	2000.0	Early Carboniferous	Weaber Group (Milligans Formation)	GDA94	-15.283604	128.954559
Vienta 1	Carlton Shelf	W002262	Petroleum	no	1540.0	Early Carboniferous	Langfield Group (Enga Sandstone)	GDA94	-15.369250	128.786717
Waggon Creek 1	Carlton Shelf	W001998	Petroleum	no	700.0	Early Carboniferous	Weaber Group (Milligans Formation)	GDA94	-15.322398	128.711781
Waggon Creek 1A	Carlton Shelf	W002108	Petroleum	no	1323.0	Late Devonian	Cockatoo Group	GDA94	-15.320243	128.710606

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

Well Name	Datum	Latitude (°)	Longitude (°)	TD (m)	Basement type	Depth to Basement (m)	Notes
Western Australia							
Berkley 1	GDA94	-14.003009	127.832634	874	dolerite	814.0	
Cambridge 1	GDA94	-14.288996	128.433879	2228	quartz dolerite	2213.5	
Pelican Island 1	GDA94	-14.770507	128.775411	1981	halite	1791.3	Ordovician-Devonian salt diapir
Sandpiper 1	GDA94	-13.313290	127.977626	1892	halite	1752.9	Ordovician-Devonian salt diapir [note 943.9 m is referred to as the halite cap rock]
Northern Territory							
Bullo River 1	?GA website	-15.595259	129.631241	970	granite [weakly altered graphic granite]	880.0	Correlate of Fitzmaurice Group?
Flat Top 1	?GA website	-12.375072	129.266754	2173.5	quartzite	2165.6	
Kinmore 1	?GA website	-14.032208	129.263735	3250	halite	3046.0	G2850A5 p.323
Moyle 1	?GA website	-14.318038	129.776510	538.6	gabbro	517.6	
Newby 1	?GA website	-11.833880	129.103169	1148.5	quartzite	1115.6	
Troubadour 1	?GA website	-9.733006	128.124976	3495	granite	3315.5	G2850A5 p.326 and GA report p.70

Attachment C: Predicted basement lithology and depths for all wells in this study.

Well Name	Well ID	Total Depth (mTVD)	Probable Basement Lithology	Basement Depth (m)	Depth to Basement from Total Depth (m)	Datum	Latitude (°)	Longitude (°)
Bonaparte 1	W001498	3209.5	Metasediment	5250	2040.5	GDA94	-15.0152299	128.7442975
Bonaparte 2	W001499	2136.0	Metasediment	4500	2364	GDA94	-15.0838407	128.7223534
Garimala 1	W001500	2553.0	Metasediment	4000	1447	GDA94	-15.1864814	128.7275712
Ningbing 1	W001501	1269.0	Metasediment	3500	2231	GDA94	-15.1805759	128.6818269
Ningbing 2	W001502	1336.0	Metasediment	3500	2164	GDA94	-15.2186313	128.6904412
Pelican Island 1	W002206	1981.0	Metasediment	7500	5519	GDA94	-14.7705074	128.7754105
Skull 1	W001908	2000.0	Metasediment	3000	1000	GDA94	-15.2836041	128.9545593
Vienta 1	W001995	1540.0	Metasediment	1750	210	GDA94	-15.3692503	128.7867168
Waggon Creek 1A	W000028	1323.0	Metasediment	3000	1677	GDA94	-15.3202426	128.7106059

Attachment D: Summary of measured rock thermal conductivity data for the Bonaparte Basin (see Appendix 2 for more details).

Sample	Well	Depth from (m)	Depth to (m)	Depth from (')	Depth to (')	Conductivity (W/mK)	Uncertainty ± (W/mK)	Formation	Lithology
DIR152	Bonaparte 1A			576' 4"/ 578' 4"	576' 8"/ 578' 8"	2.94	0.32	Point Spring Sandstone	salmon pink medium-grained sst
DIR153	Bonaparte 1A			689' 8"	690'	2.19	0.02	Tanmurra Formation	grey slt
DIR154	Bonaparte 2			3948' 4"/ 3940' 4"	3948' 8"/ 3940' 8"	3.92	0.58	Milligans Formation	heterolithic fine-grained light grey sst and dark grey slt; slumping features; whispy slt in the sst
DIR155	Bonaparte 1A			9267' 4"/ 9263' 4"	9267' 8"/ 9263' 8"	1.73	0.06	Burt Range Formation	heterolithic fine-grained cream sst and greenish grey slt
DIR156	Bonaparte 1A			10476' 4"	10476' 8"	5.09	0.51	Cockatoo Group	?grey quartzite
DIR157	Laminaria East 1	3249.70	3249.90			1.24	0.03	Frigate Shale	grey shale
DIR161	Turtle 1	2488.20	2488.50			4.11	0.08	Bonaparte Formation	grey fine- to medium-grained sst
DIR162	Turtle 1	929.00	929.30			2.60	0.05	Keyling Formation	sst, oil impregnated; no non oil sands within core
DIR163	Turtle 1	932.45	932.70			2.38	0.05	Keyling Formation	heterolithic dark grey slt/light grey sst; whispy slt
DIR164	Turtle 1	1441.65	1441.85			2.29	0.31	Treachery Shale	interbedded light grey sst and dark grey slt
DIR165	Turtle 1	1599.65	1599.95			3.19	0.05	Kuriyippi Formation	light grey sst
DIR166	Turtle 1	1601.50	1601.75			2.35	0.09	Kuriyippi Formation	light grey sst and dark grey slt; mottled/bioturbated
DIR167	Turtle 1	1612.00	1612.30			2.87	0.39	Kuriyippi Formation	grey diamictite?

Attachment E: Formation conductivities for the Bonaparte Basin based on lithology mixing methods. Notes refer to lithology mixing proportions and other reports generated by HDR for this same project.

Formation	Conductivity (W/mK)	Uncertainty ± (W/mK)	Notes
Alluvium	1.42	0.14	Formation not tested; use Beardsmore (2005) value
Fossil Head Formation	2.29	0.46	Formation not tested; use Treachery Shale
Keyling Formation	2.48	0.05	Value calculated from DIR162 [50% of the representative lithology], and DIR163 [50% of the representative lithology]
Keep Inlet Formation	2.12	0.42	Formation not tested; use Carnarvon Basin (HDR, 2010a): undifferentiated Byro Group
Treachery Shale	2.29	0.31	Value based on DIR164
Kuriyippi Formation	2.76	0.17	Value calculated from DIR165 [33.3% of the representative lithology], DIR166 [33.3% of the representative lithology] and DIR167 [33.3% of the representative lithology]
Point Spring Sandstone	2.94	0.32	Value based on DIR152
Tanmurra Formation	2.19	0.02	Value based on DIR153
Burvill Formation	3.28	0.66	Formation not tested; use Carnarvon Basin (HDR, 2010a): Quail Formation
Milligans Formation	2.20	0.50	Value of 3.92 ± 0.58 W/mK from DIR154 considered anomalous as this specimen came from a sandy section of the formation. Predominantly shale thus value of 2.2 ± 0.5 W/mK assigned. See section 4.7 of this report.
Bonaparte Formation	4.11	0.08	Value based on DIR161
Langfield Group	2.38	0.48	Formation not tested; use Canning Basin (Driscoll et al., 2009): Fairfield Group [25% Laurel Formation, 25% Yellow Drum Formation, 25% Gumhole Formation and 25% Luluigui Formation]
Burt Range Formation	1.73	0.06	Value based on DIR155
Ningbing Group	3.23	0.65	Formation not tested; use Canning Basin (Driscoll et al., 2009): 50% DIR087 Nullara Limestone & 50% DIR076 Windjana Limestone
Cockatoo Group	5.09	0.51	Value based on DIR156
?Palaeozoic Halite	5.25	1.05	Formation not tested; use Officer Basin (HDR, 2010b): DIR188 Browne Formation

Attachment F: Estimated heat generation for metasedimentary rock samples adjacent to the onshore Bonaparte 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 Gen. from isotopic abundance ratios (μW/m^3)
Halls Creek Region	Halls Creek Inlier	-16.703251	128.388739	GDA94	quartzite	orthoquartzite	1.83	15200	1	3	2.48	0.57
Halls Creek Region	Halls Creek Orogen	-17.747405	127.828807	GDA94	hornfels	hornsfelsed metasediment	0.3	2500	2	3	2.48	0.70
Halls Creek Region	-	-16.703251	128.388739	GDA94	sandstone	tuff sandstone [informal name: Argyle (AK1) Pipe]	4.22	35000	3	14	2.48	1.94
Halls Creek Region	Halls Creek Inlier	-16.703251	128.388739	GDA94	shale	shale at contact; ferruginised	8.47	70300	5	21	2.48	3.18
Halls Creek Region	Halls Creek Inlier	-16.703251	128.388739	GDA94	quartzite	-	0.26	2200	1.5	2	2.48	0.51
Halls Creek Region	Halls Creek Orogen	-17.828686	127.819785	GDA94	schist	garnet schist	2.79	23200	3	23	2.48	2.42
Halls Creek Region	Halls Creek Orogen	-17.650010	127.912485	GDA94	hornfels	metapelite	4.16	34500	2	26	2.48	2.47
Halls Creek Region	Halls Creek Orogen	-17.460776	128.170704	GDA94	sandstone	volcaniclastic	3.25	27000	6	24	2.48	3.24
Halls Creek Region	Halls Creek Orogen	-17.839853	127.840358	GDA94	iron formation	folded banded iron formation	0.39	3200	3	3	2.48	0.94
Halls Creek Region	Halls Creek Orogen	-17.232083	128.032148	GDA94	ironstone	limonite-hematite gossan [informal name: Norton intrusion]	0.4	3300	6	4	2.48	1.73
Halls Creek Region	Halls Creek Orogen	-17.213085	128.047737	GDA94	ironstone	vuggy limonite-hematite gossan [informal name: Norton intrusion]	1.52	12600	3.5	9	2.48	1.54

Halls Creek Region	Halls Creek Orogen	-17.288988	128.187184	GDA94	ironstone	malachite-chrysocolla coated limonite gossan [informal name: Corkwood intrusion]	0.35	2900	2	2	2.48	0.64
Halls Creek Region	Halls Creek Orogen	-17.963513	127.947439	GDA94	turbidite	-	6.92	57400	7	23	2.48	3.68
Halls Creek Region	Halls Creek Orogen	-17.963087	127.947139	GDA94	greywacke	low-grade metamorphic	3.73	31000	5	20	2.48	2.77
Halls Creek Region	Halls Creek Orogen	-17.458101	128.043880	GDA94	pelite	layered fine to medium-grained metapelite QZ-?KFS-PL-BT-GNT	1.23	10200	1.6	28.8	2.48	2.35
Halls Creek Region	Halls Creek Orogen	-17.455112	128.023932	GDA94	pelite	well foliated SIL-CRD pelite	2.49	20700	0.7	7.2	2.48	0.82

Median	**1.83**

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

Well Name	Total Depth (m)	Probable 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)
Bonaparte 1	3209.5	Metasediment	5250.0	2040.5	GDA94	-15.015230	128.744298	n	n	2	60	8.8
Bonaparte 2	2136.0	Metasediment	4500.0	2364.0	GDA94	-15.083841	128.722353	n	n	2	65	11.0
Garimala 1	2553.0	Metasediment	4000.0	1447.0	GDA94	-15.186481	128.727571	y	y	5	83	13.3
Ningbing 1	1269.0	Metasediment	3500.0	2231.0	GDA94	-15.180576	128.681827	y	y	5	99	19.3
Ningbing 2	1336.0	Metasediment	3500.0	2164.0	GDA94	-15.218631	128.690441	y	y	5	95	18.6
Pelican Island 1	1981.0	Metasediment	7500.0	5519.0	GDA94	-14.770507	128.775411	n	y	4	69	8.3
Skull 1	2000.0	Metasediment	3000.0	1000.0	GDA94	-15.283604	128.954559	n	y	4	75	13.4
Vienta 1	1540.0	Metasediment	1750.0	210.0	GDA94	-15.369250	128.786717	y	y	5	76	12.6
Waggon Creek 1A	1323.0	Metasediment	3000.0	1677.0	GDA94	-15.320243	128.710606	y	y	5	103	17.2

Appendix 1

Heat flow models and temperature data used for nine wells in the Bonaparte Basin Report DMP0260909

HDR

July 2010

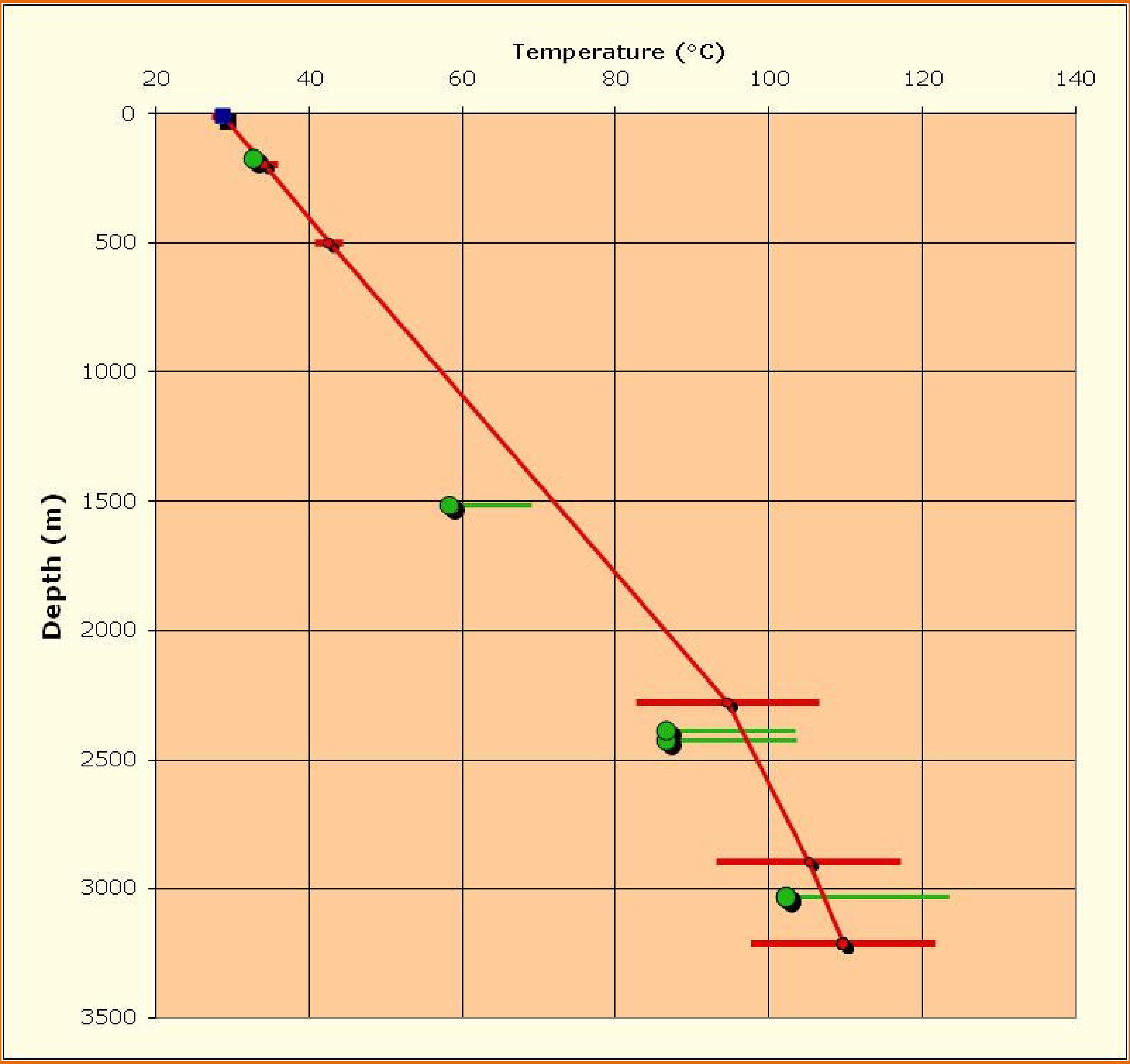
An appendix to the report - Geothermal Energy Potential in Selected Areas of Western Australia (Bonaparte Basin); prepared for the Department of Mines and Petroleum, Western Australia.

Number of layers	6	Up to 50	**Heat flow:**	60	± 8.8 mW/m2
"Depth" to ground level	5	"KB height"			
Total Depth (m)	3210	From driling datum			
Surface temp. (°C)	28.65	**Bonaparte 1**			
Uncertainty in surface T	1.5	±°C			

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m^3)	Thickness (m)
1	Keep Inlet Formation	5	2.12 ± 0.42	0	189
2	Tanmurra Formation	194	2.19 ± 0.02	0	303
3	Milligans Formation	497	2.20 ± 0.50	0	1783
4	Bonaparte Formation	2280	4.11 ± 0.08	0	613
5	Cockatoo Group	2893	5.09 ± 0.51	0	316.5
6	Cockatoo Group	3209.5	5.09 ± 0.51	0	0.5

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
169.47	32.78	0	1.1863	BHT [time since circ. unknown]
1511.81	58.33	0	10.583	BHT [time since circ. unknown]
3032.15	102.22	0	21.225	BHT [time since circ. unknown]
2424.99	86.67	0	16.975	BHT [time since circ. unknown]
2386.58	86.67	0	16.706	BHT [time since circ. unknown]
3032.46	102.22	0	21.227	BHT [time since circ. unknown]



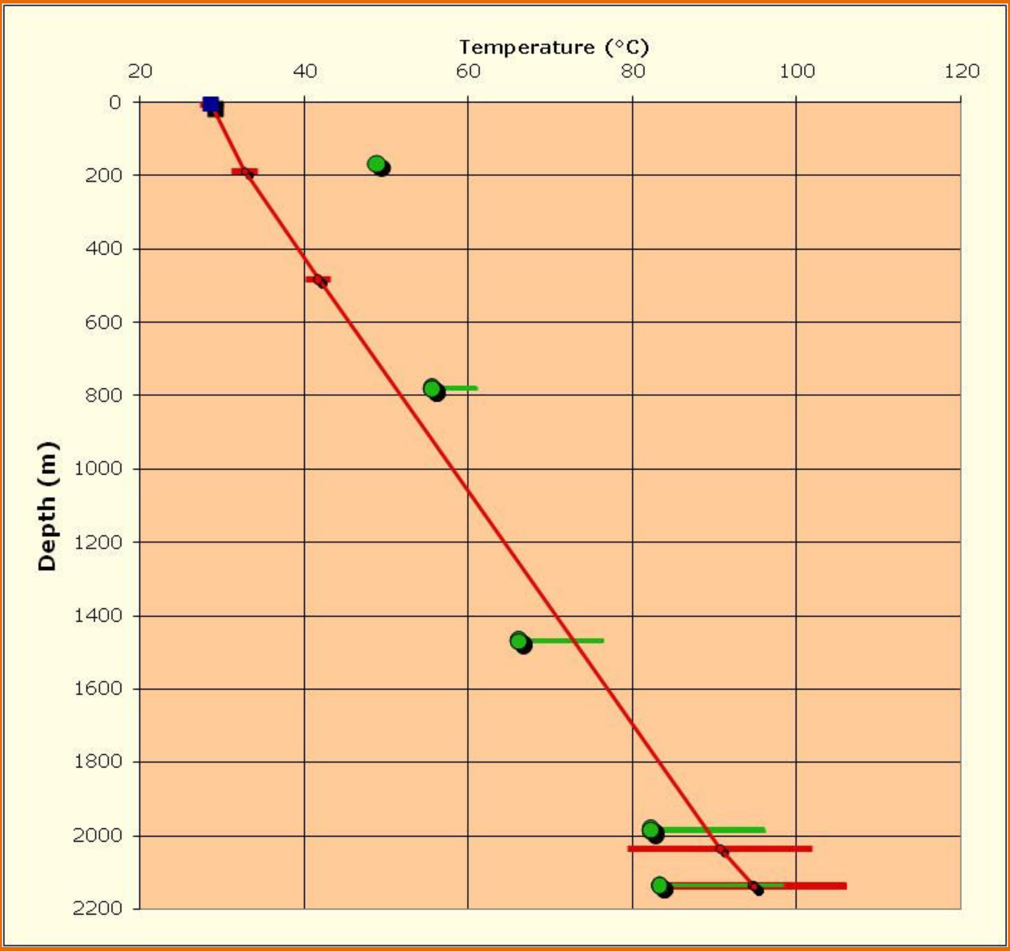
Bonaparte 1

Number of layers	5	Up to 50	Heat flow:	65 ± 11.0 mW/m2
"Depth" to ground level	5.03	"KB height"		
Total Depth (m)	2137	From driling datum		
Surface temp. (°C)	28.65	Bonaparte 2		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Point Spring Sandstone	5.03	2.94 ± 0.32	0	179.97
2	Tanmurra Formation	185	2.19 ± 0.02	0	296
3	Milligans Formation	481	2.20 ± 0.50	0	1553.5
4	Langfield Group [Burt Range Formation]	2034.5	1.73 ± 0.06	0	101.5
5	Langfield Group [Burt Range Formation]	2136	1.73 ± 0.06	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
778.15	55.56	0	5.4471	BHT [time since circ. unknown]
1466.09	66.11	0	10.263	BHT [time since circ. unknown]
1981.81	82.22	0	13.873	BHT [time since circ. unknown]
2133.6	83.33	0	14.935	BHT [time since circ. unknown]
777.24	55.56	0	5.4407	BHT [time since circ. unknown]
778.76	55.56	0	5.4513	BHT [time since circ. unknown]
1466.7	66.11	0	10.267	BHT [time since circ. unknown]
2134.21	83.33	0	14.939	BHT [time since circ. unknown]
1986.38	82.22	0	13.905	BHT [time since circ. unknown]
165.2	48.89	0	1.1564	BHT [time since circ. unknown]
779.68	55.56	0	5.4578	BHT [time since circ. unknown]
1467.61	66.11	0	10.273	BHT [time since circ. unknown]
1982.72	82.22	0	13.879	BHT [time since circ. unknown]
2135.12	83.33	0	14.946	BHT [time since circ. unknown]



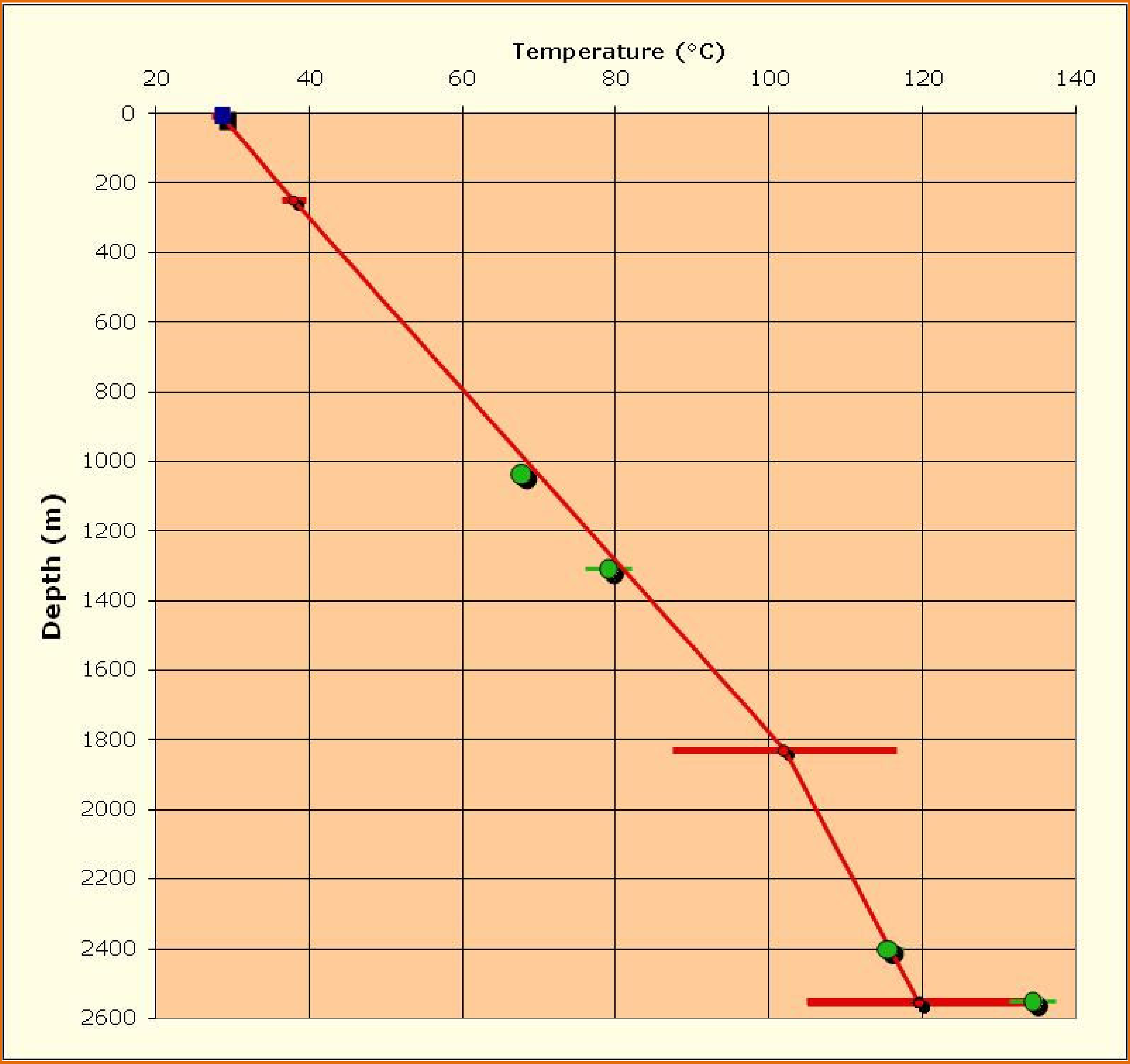
Bonaparte 2

Number of layers	4	Up to 50	**Heat flow:**	83	± 13.3 mW/m2
"Depth" to ground level	5.7	"KB height"			
Total Depth (m)	2554	From driling datum			
Surface temp. (°C)	28.65	**Garimala 1**			
Uncertainty in surface T	1.5	±°C			

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A ($\mu W/m^3$)	Thickness (m)
1	Tanmurra Formation	5.7	2.19 ± 0.02	0	243.3
2	Milligans Formation	249	2.20 ± 0.50	0	1580
3	Bonaparte Formation	1829	4.11 ± 0.08	0	724
4	Bonaparte Formation	2553	4.11 ± 0.08	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1308.5	79.05	3	3	Horner [4 values]
2552	134.43	3	3	Horner [4 values]
1035.68	67.78	0	2	DST1 [79.5 m rat hole mud]
2399.8	115.56	0	2	DST2 [gas flowed to surface - max rate 0.75 mmcf/d; sample lost]



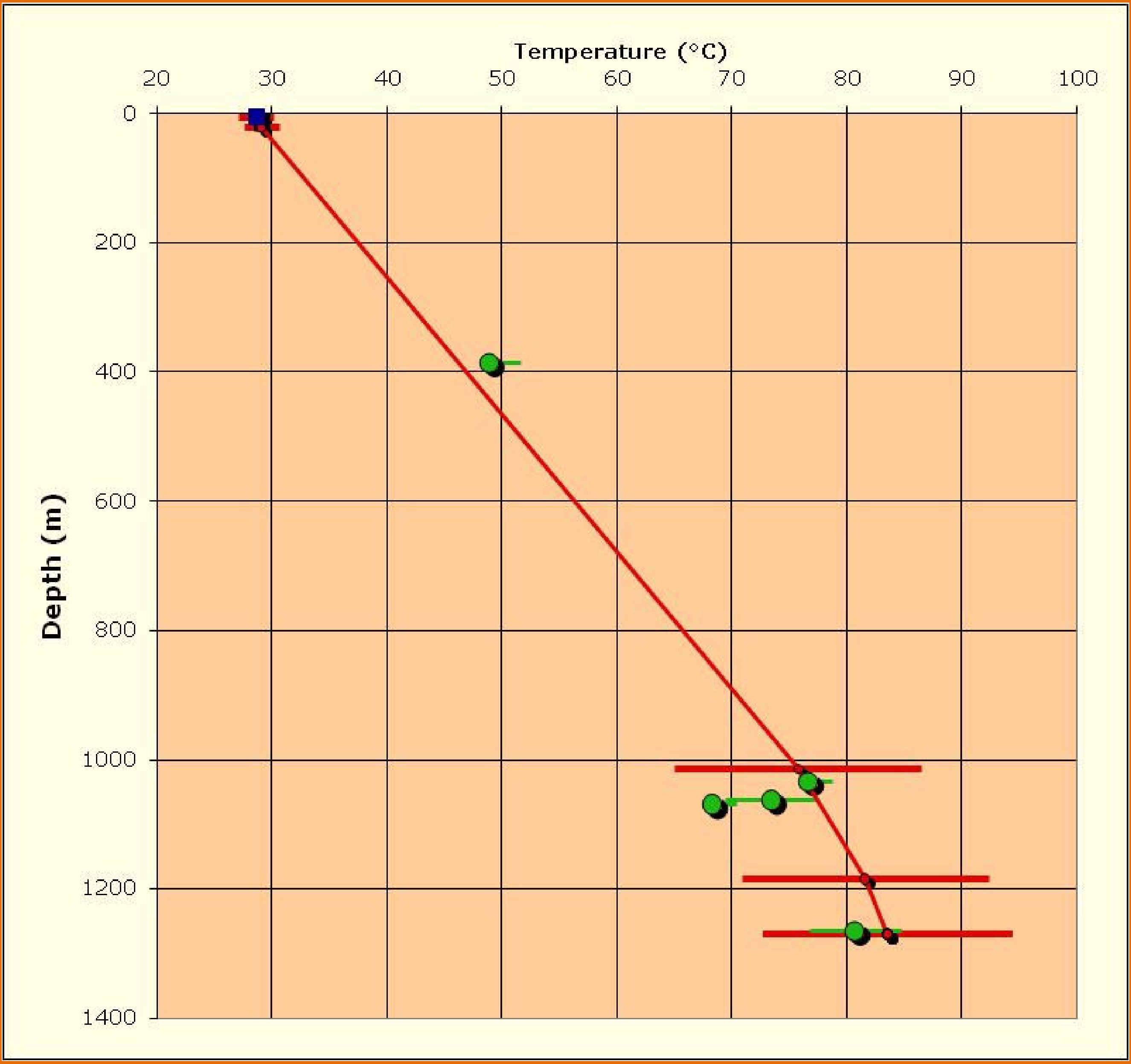
Garimala 1

Number of layers	5	Up to 50	**Heat flow:**	99 ± 19.3 mW/m2
"Depth" to ground level	6	"KB height"		
Total Depth (m)	1270	From driling datum		
Surface temp. (°C)	28.65	**Ningbing 1**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A ($\mu W/m^3$)	Thickness (m)
1	Burvill Formation	6	3.28 ± 0.66	0	15
2	Milligans Formation	21	2.20 ± 0.50	0	992
3	Ningbing Group	1013	3.23 ± 0.65	0	171
4	Cockatoo Group	1184	5.09 ± 0.51	0	85
5	Cockatoo Group	1269	5.09 ± 0.51	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
385	48.89	0	2.695	BHT [time since circ. 2:30 hour]
1062.2	73.44	4	4	Horner [3 values]
1265	80.74	4	4	Horner [3 values]
1033.06	76.67	0	2	DST1 [misrun, test tool stuck; recovered 56.83 m rat hole mud; tool open for 3 minutes]
1068.54	68.33	0	2	DST2 [recovered 486 m (13.2 bbls) drilling mud; 200 m (7 bbls) gas cut muddy water]



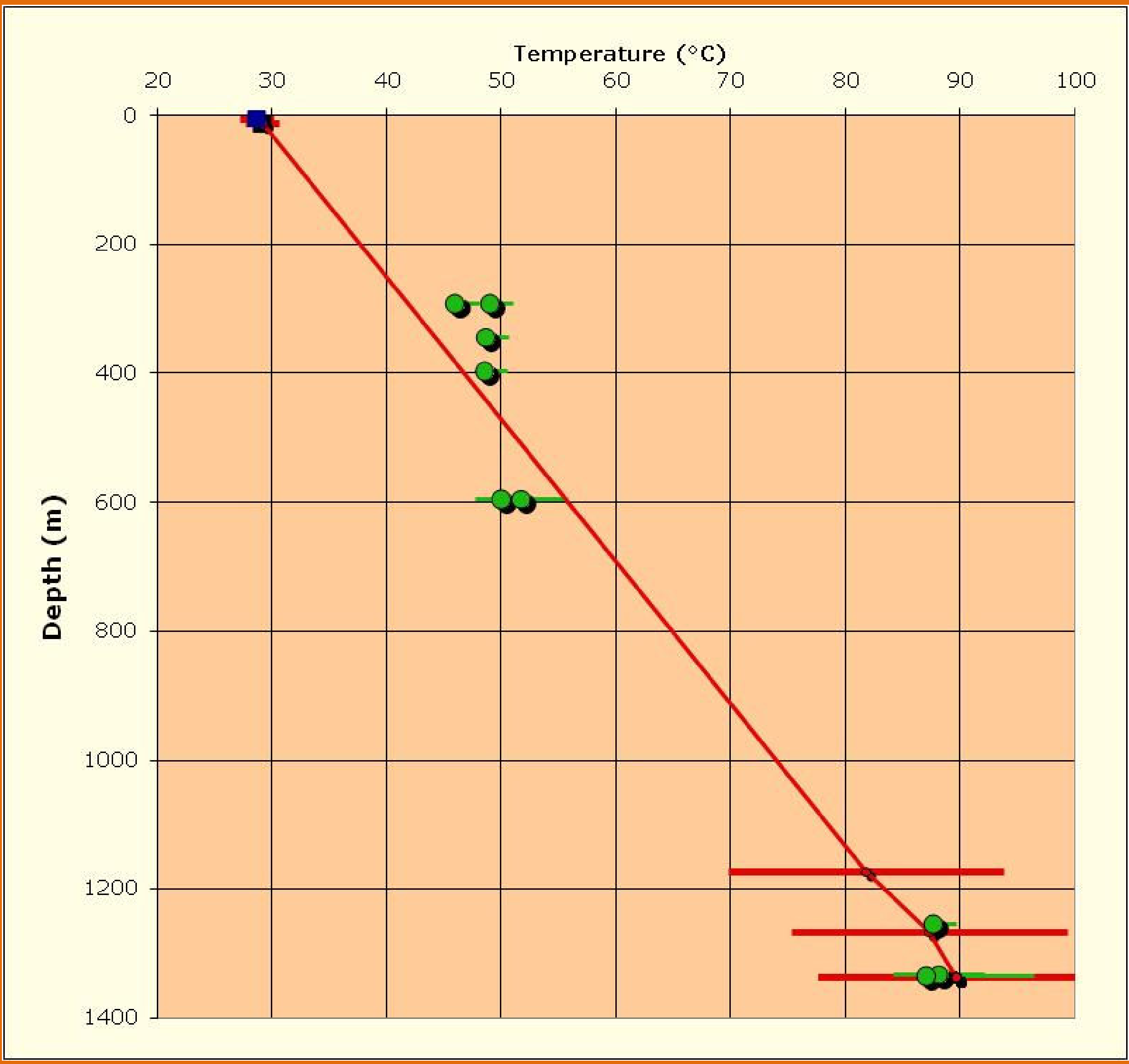
Ningbing 1

Number of layers	5	Up to 50	**Heat flow:**	95 ± 18.6 mW/m2
"Depth" to ground level	4.5	"KB height"		
Total Depth (m)	1337	From driling datum		
Surface temp. (°C)	28.65	**Ningbing 2**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A ($\mu W/m^3$)	Thickness (m)
1	Alluvium [clay]	4.5	1.42 ± 0.14	0	7.5
2	Milligans Formation	12	2.20 ± 0.50	0	1160
3	Langfield Group [Burt Range Formation]	1172	1.73 ± 0.06	0	94
4	Ningbing Group	1266	3.23 ± 0.65	0	70
5	Ningbing Group	1336	3.23 ± 0.65	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
593.3	51.72	4	4	Horner [3 values]
1331.5	88.07	4	4	Horner [3 values]
594	50	0	4.158	BHT
1334	87	0	9.338	BHT
291.2	49	0	2	DST1 [no recovery - misrun, packer seat failure]
291.2	46	0	2	DST1A [no recovery - misrun, packer seat failure]
395.33	48.47	0	2	DST2 [recovered 320 m gas cut mud/formation fluid; tool open for 90 minutes]
1253.64	87.66	0	2	DST4 [recovered 190 m diluted drilling mud; 290 m gas cut watery mud; 584 m gas cut formation fluid; tool open for 61 minutes]
342.6	48.62	0	2	DST5 [recovered gas flow at RTSTM; 50 m drilling mud; 50 m gas cut watery mud; 100 m gas cut formation fluid; tool open for 64 minutes]



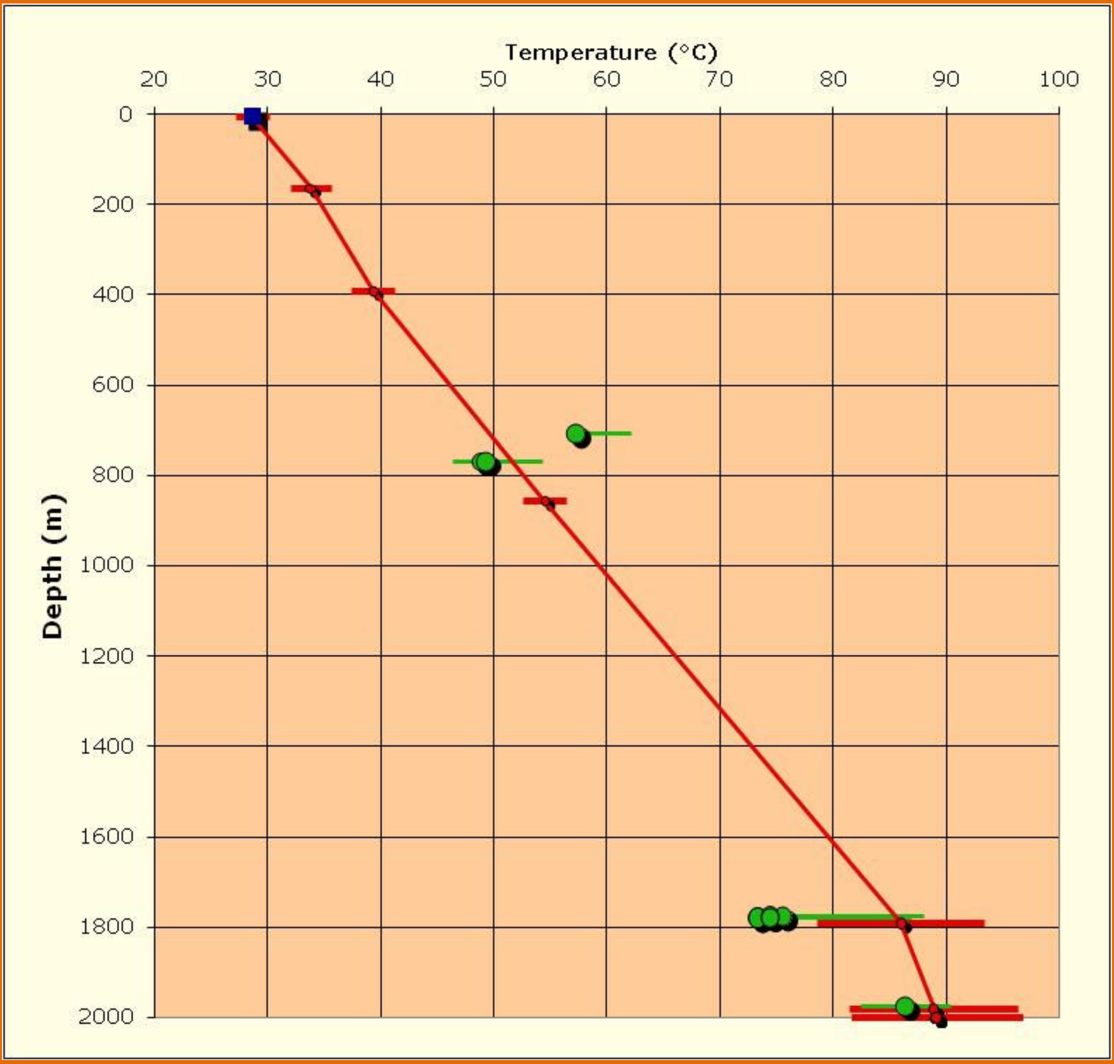
Ningbing 2

Number of layers	6	Up to 50	**Heat flow:**	69 ± 8.3 mW/m2
"Depth" to ground level	4.75	"KB height"		
Total Depth (m)	2000	From driling datum		
Surface temp. (°C)	28.65	**Pelican Island 1**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top	Cond @ 30°C (W/mK)	A (µW/m³)	Thickness (m)
1	Keep Inlet Formation	4.75	2.12 ± 0.42	0	157.25
2	Point Spring Sandstone	162	2.94 ± 0.32	0	228
3	Tanmurra Formation	390	2.19 ± 0.02	0	466
4	Milligans Formation	856	2.20 ± 0.50	0	935
5	Halite	1791	5.25 ± 1.05	0	190.2
6	Halite	1981.2	5.25 ± 1.05	0	18.8

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
707.14	57.22	0	4.95	Temp Log [time since circ. unknown]
766.8	48.89	0	5.3676	BHT [time since circ. unknown]
767.5	49.27	3	3	Horner [4 values]
1974.9	86.34	4	4	Horner [3 values]
1779.73	73.33	0	12.458	BHT [time since circ. 3:00 hour]
1778.51	73.33	0	12.45	BHT [time since circ. 6:30 hour]
1779.42	73.33	0	12.456	BHT [time since circ. 7:00 hour]
1776.98	75.56	0	12.439	BHT [time since circ. 8:00 hour]
1776.37	74.44	0	12.435	BHT [time since circ. 12:00 hour]
1777.9	74.44	0	12.445	BHT [time since circ. 24:00 hour]



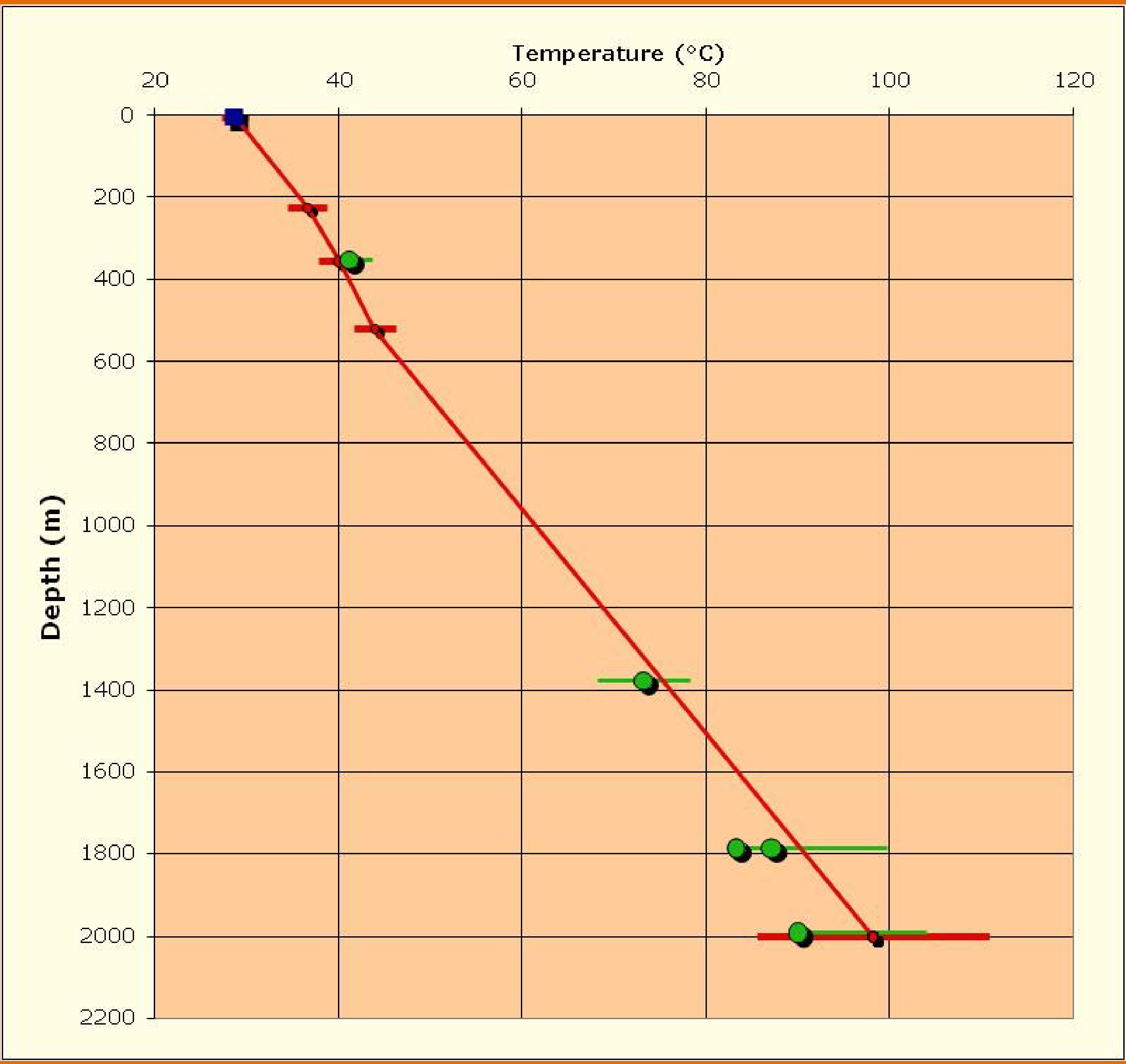
Pelican Island 1

Number of layers	5	Up to 50	Heat flow:	75	± 13.4 mW/m2
"Depth" to ground level	3.5	"KB height"			
Total Depth (m)	2001	From driling datum			
Surface temp. (°C)	28.65	Skull 1			
Uncertainty in surface T	1.5	±°C			

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Keep Inlet Formation	3.5	2.12 ± 0.42	0	221.5
2	Point Spring Sandstone	225	2.94 ± 0.32	0	129
3	Burvill Formation	354	3.28 ± 0.66	0	166
4	Milligans Formation	520	2.20 ± 0.50	0	1480
5	Milligans Formation	2000	2.20 ± 0.50	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1375.6	73.19	5	5	Horner [2 values]
349.9	41.11	0	2.4493	BHT [time since circ. 5:11 hour]
1785	83.33	0	12.495	BHT [time since circ. 17:43]
1785.3	83.33	0	12.497	BHT [time since circ. unknown]
1785.3	87.22	0	12.497	BHT [time since circ. >20:15]
1992	90	0	13.944	BHT [time since circ. 5:39 hour]



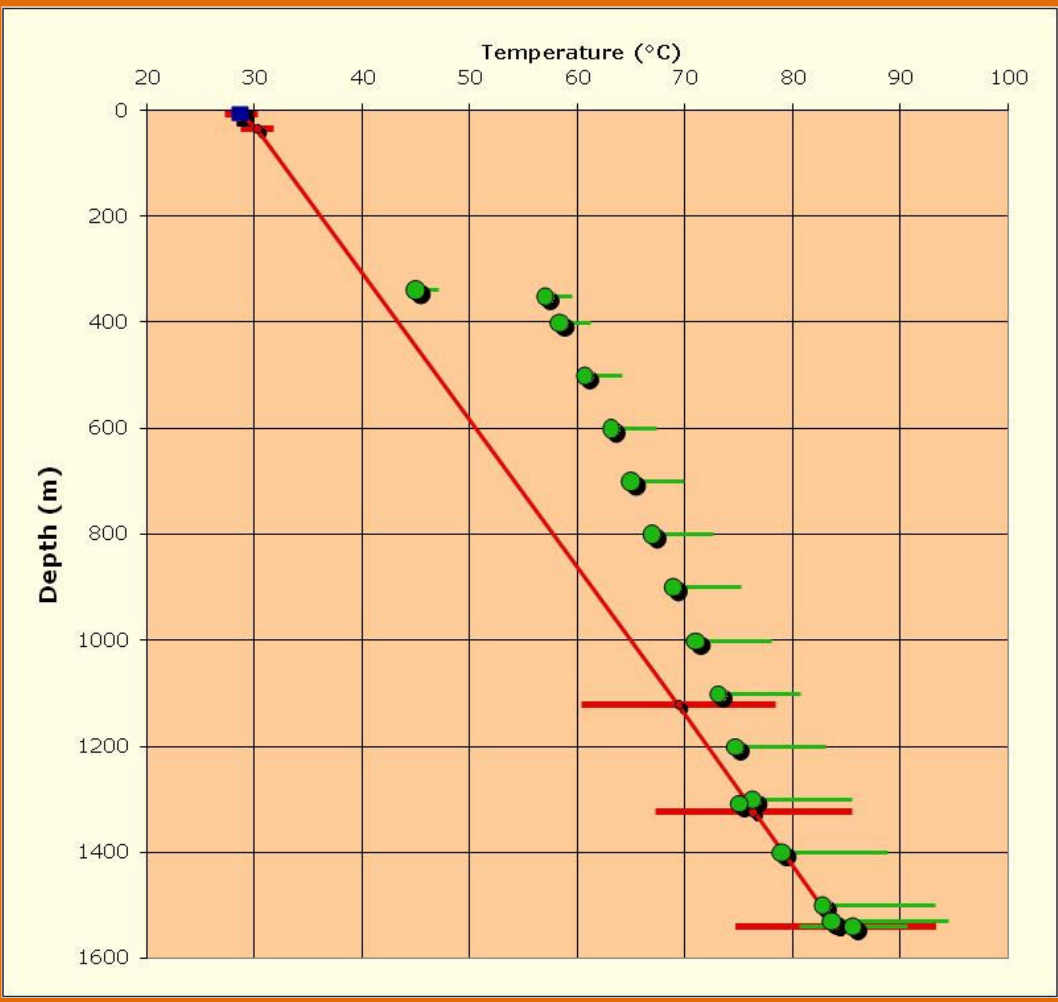
Skull 1

Number of layers	6	Up to 50 **Heat flow:** 76 ± 12.6 mW/m2
"Depth" to ground level	4.75	"KB height"
Total Depth (m)	1541	From driling datum
Surface temp. (°C)	28.65	**Vienta 1**
Uncertainty in surface T	1.5	±°C

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Alluvium [sand]	4.75	1.42 ± 0.14	0	2
2	Alluvium [siltstone]	6.75	1.42 ± 0.14	0	27.25
3	Milligans Formation	34	2.20 ± 0.50	0	1088
4	Langfield Group [Septimus Limestone]	1122	2.38 ± 0.48	0	201
5	Langfield Group [Enga Sandstone]	1323	2.38 ± 0.48	0	217
6	Langfield Group [Enga Sandstone]	1540	2.38 ± 0.48	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1540	85.57	5	5	Horner [2 values]
350	56.944	0	2.45	Temp log
400	58.355	0	2.8	Temp log
500	60.618	0	3.5	Temp log
600	63.071	0	4.2	Temp log
700	65.001	0	4.9	Temp log
800	66.914	0	5.6	Temp log
900	68.888	0	6.3	Temp log
1000	70.986	0	7	Temp log
1100	72.991	0	7.7	Temp log
1200	74.623	0	8.4	Temp log
1300	76.289	0	9.1	Temp log
1400	78.965	0	9.8	Temp log
1500	82.7	0	10.5	Temp log
1530	83.626	0	10.71	Temp log
338	45	0	2	DST1 [gas flow to surface RTSTM]
1307	75	0	2	DST2 [recovered gas 2 hour period on 6.35 mm choke; 258,000 cfpd declinging to 169,000 cfpd]



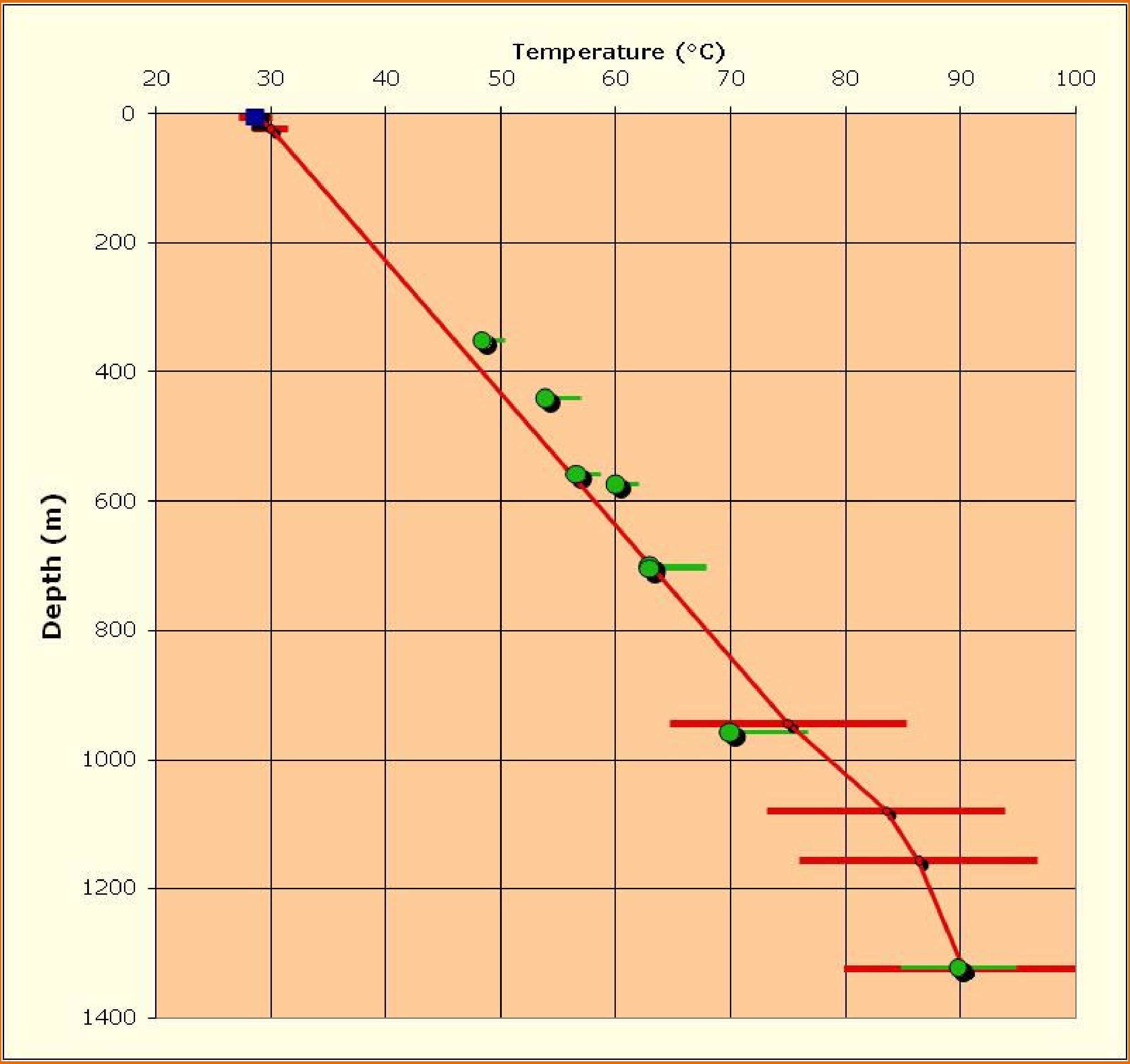
Vienta 1

Number of layers	6	Up to 50	**Heat flow:**	103 ± 17.2 mW/m2
"Depth" to ground level	4.5	"KB height"		
Total Depth (m)	1324	From driling datum		
Surface temp. (°C)	28.65	**Waggon Creek 1A**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m^3)	Thickness (m)
1	Quaternary sands	4.5	1.42 ± 0.14	0	17.5
2	Milligans Formation	22	2.20 ± 0.50	0	921
3	Langfield Group [Burt Range Formation]	943	1.73 ± 0.06	0	135
4	Ningbing Group	1078	3.23 ± 0.65	0	78
5	Cockatoo Group	1156	5.09 ± 0.51	0	167
6	Cockatoo Group	1323	5.09 ± 0.51	0	1

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1320.75	89.79	5	5	Horner [2 values]
439.5	53.9	0	3.0765	BHT [time since circ. 8:42 hour]
956.46	70	0	6.6952	DST [gas recovered at rate too small to measure]
699	63	0	4.893	BHT [time since circ. 10:10 hour]
702.5	63	0	4.9175	BHT [time since circ. 12:40 hour]
349	48.36	0	2	DST1 [recovered 1.34 mmcf/d on 0.5" choke over 2.5 hours]
556.56	56.61	0	2	DST2 [formation tight, no recovery]
572.78	59.97	0	2	DST3 [recovered 0.952 mmcf/d and 3.4 bls oil-cut water on 3/8" choke over 2.5 hours]
				Data from Waggon Creek 1



Waggon Creek 1A

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Appendix 2

Thermal conductivity of core samples DIR089-DIR207

An appendix to the report Geothermal Energy Potential in Selected Areas of Western Australia (Bonaparte 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 bioturbated [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 bioturbated [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 bedding	2814.80	2815.05			DIR125
Kennedy Range 1	Carnarvon	Moogooloo Sandstone	light tan grey coarse-grained sst with minor carbonaceous 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 fossiliferous	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 fossiliferous	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.

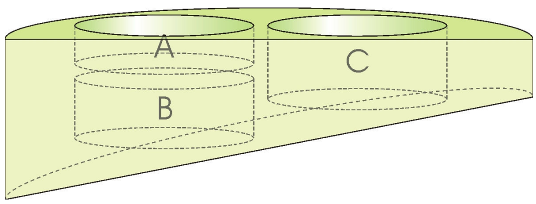
Where possible, three prisms were cut from each core specimen, each approximately ⅓ to ½ the length of the sample in thickness, and each sample was ground flat and polished. These are indicated on Table 2 by the description 'Whole rock'.

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.

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