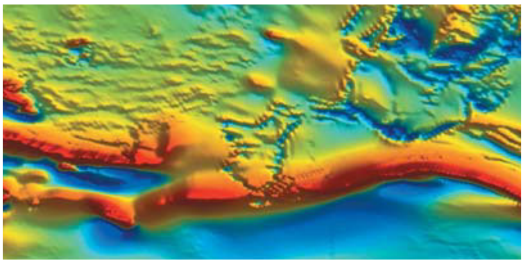
Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2010/22

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

by
Hot Dry Rocks Pty Ltd


Geological Survey of Western Australia

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Hot Dry Rocks Pty Ltd[1]

[1] Geothermal Energy Consultants, Post Office Box 251, South Yarra, Vic 3141

Perth 2010

Geological Survey of
Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon. Norman Moore MLC

DIRECTOR GENERAL, DEPARTMENT OF MINES AND PETROLEUM
Richard Sellers

ACTINGT EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Rick Rogerson

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Hot Dry Rocks Pty Ltd
Geothermal Energy Consultants

HEAD OFFICE
PO Box 251
South Yarra, Vic 3141
Australia
T +61 3 9867 4078
F +61 3 9279 3955
E info@hotdryrocks.com
W www.hotdryrocks.com

ABN: 12 114 617 622

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Geothermal Energy Potential in Selected Areas of Western Australia (Officer 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 Australia portion of the Officer Basin, referred to as the Western Officer Basin.16 wells were assessed in detail for heat flow modelling and temperature prediction at depths to 5,000 m. Of these 16 wells, only 14 had sufficient data to enable the modelling of heat flow.

The principle findings of this report are:-

- Measured rock thermal conductivities for 40 core samples collected from the Western Officer Basin range from 1.25–5.54 W/mK. These data were crucial for the development of 1D heat flow models to predict the depth to selected isotherms. The majority of the samples in the deeper section of the Officer Basin were collected from Empress 1A. It is debatable as to how representative these lithologies are of the wider Western Officer Basin.
- Apparent surface heat flow in the Western Officer Basin ranges from 33–95 mW/m^2 with a median value of 52 mW/m^2. This value is lower than the Australian median value of 64.5 mW/m^2 from the global heat flow database and considerably lower than the Perth and Canning basins median values of 76.5 mW/m^2 and 68 mW/m^2, respectively, recorded in previous HDR reports.
- The Western Officer Basin covers an area of approximately 300,000 km^2. The paucity of geological and geophysical data in large swathes of the Western Officer Basin results in the geothermal prospectivity of these areas remaining unknown. Existing water and minerals bores may provide additional data and HDR suggests a concerted effort to locate all bores. DMP should also

consider collecting temperature data from minerals and petroleum companies that are planning new bores.

- Those parts of the Western Officer Basin for which data exist suggest decreasing surface heat flow towards the centre of the basin. The lowest apparent heat flow (<60 mW/m^2) is centred in the eastern Gibson, Yowalga and northern Lennis areas. Areas of higher heat flow appear to lie on the margins of the basin, most notably the Savory area and Waigan area. Elevated apparent heat flow in the Savory area is quite likely an artefact of the gridding process.

- The 150°C isotherm appears to lie at greater than 5,000 m depth over most of the Western Officer Basin, implying limited potential for EGS in current economic circumstances.

- The 150°C isotherm apparently coincidents in most areas with Mesoproterozoic basement, which is highly unlikely to preserve any natural permeability, thus negating the potential for Hot Sedimentary Aquifer (HSA) geothermal systems.

- There is a lack of regional-scale stress data, which means that no conclusions can be drawn in regards to the potential effects of the local *in situ* stress field on EGS developments. Clarification of this issue will require that the local stress field be determined at individual well locations.

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

Authors

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

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1. Introduction

The Department of Mines and Petroleum (DMP) provided Hot Dry Rocks Pty Ltd (HDR) with basic data for 74 wells in the Bonaparte, Browse, Carnarvon and Officer basins (Figure 1). Data included 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 Australia portion of the Officer Basin, referred to as the Western Officer Basin. An initial 17 wells were highlighted by DMP for this study. HDR incorporated data from Kanpa-1 into a model of Kanpa-1A, so this report relates to 16 wells (Attachment A). An additional 17 wells have been drilled in the Western Officer Basin (Attachment B), but these are not reported on in this document.

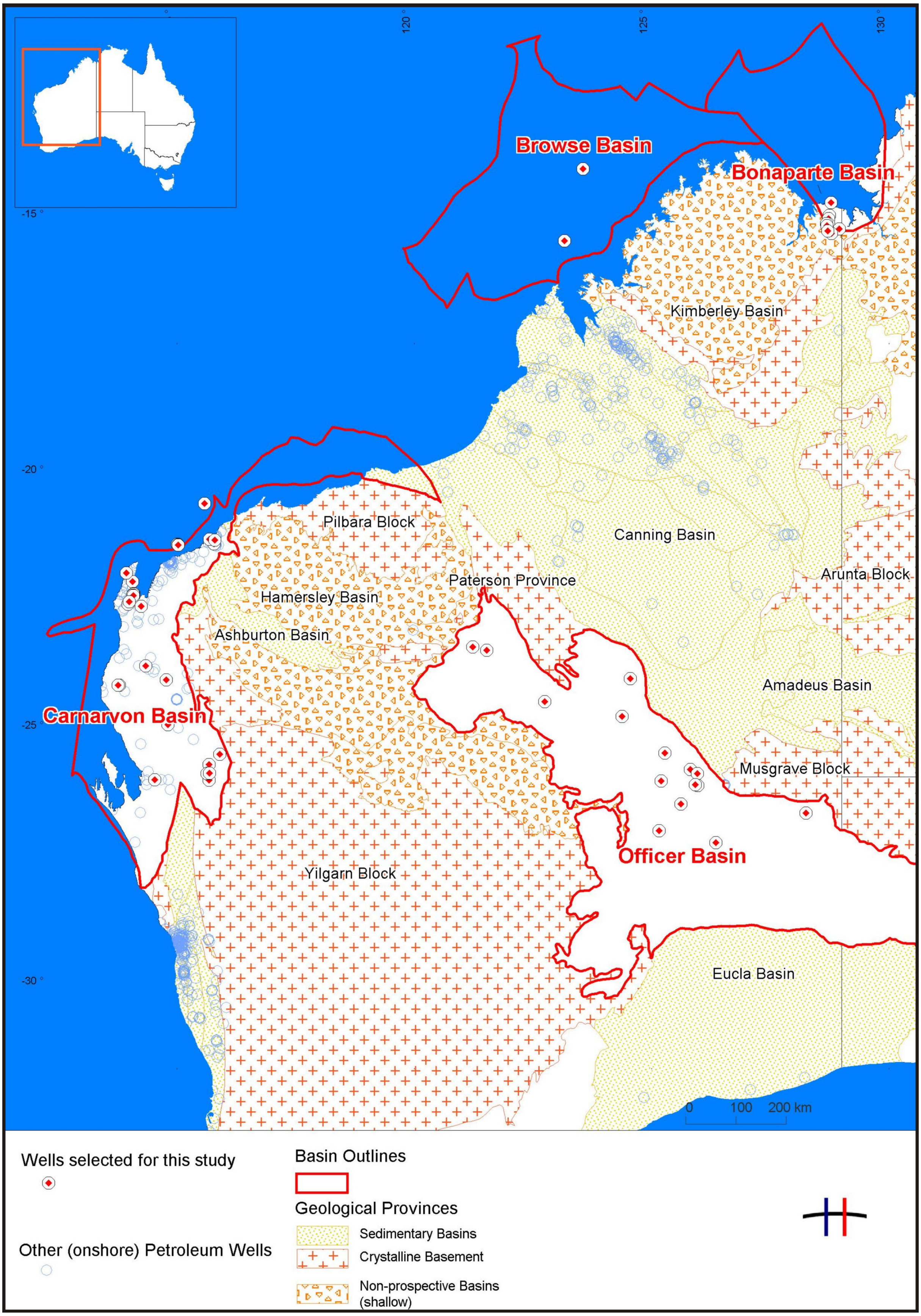

Figure 1: Location of the Bonaparte, Browse, Carnarvon and Officer basins, Western Australia (individual basin polygons modified from Geoscience Australia databases).

2. Officer Basin Geological Setting

The Officer Basin (Figure 2) covers a total area of approximately 525,000 km^2, of which some 225,000 km^2 lies within South Australia (referred to as the Eastern Officer Basin) and 300,000 km^2 within Western Australia (the Western Officer Basin). This report focuses only on the Western Officer Basin.

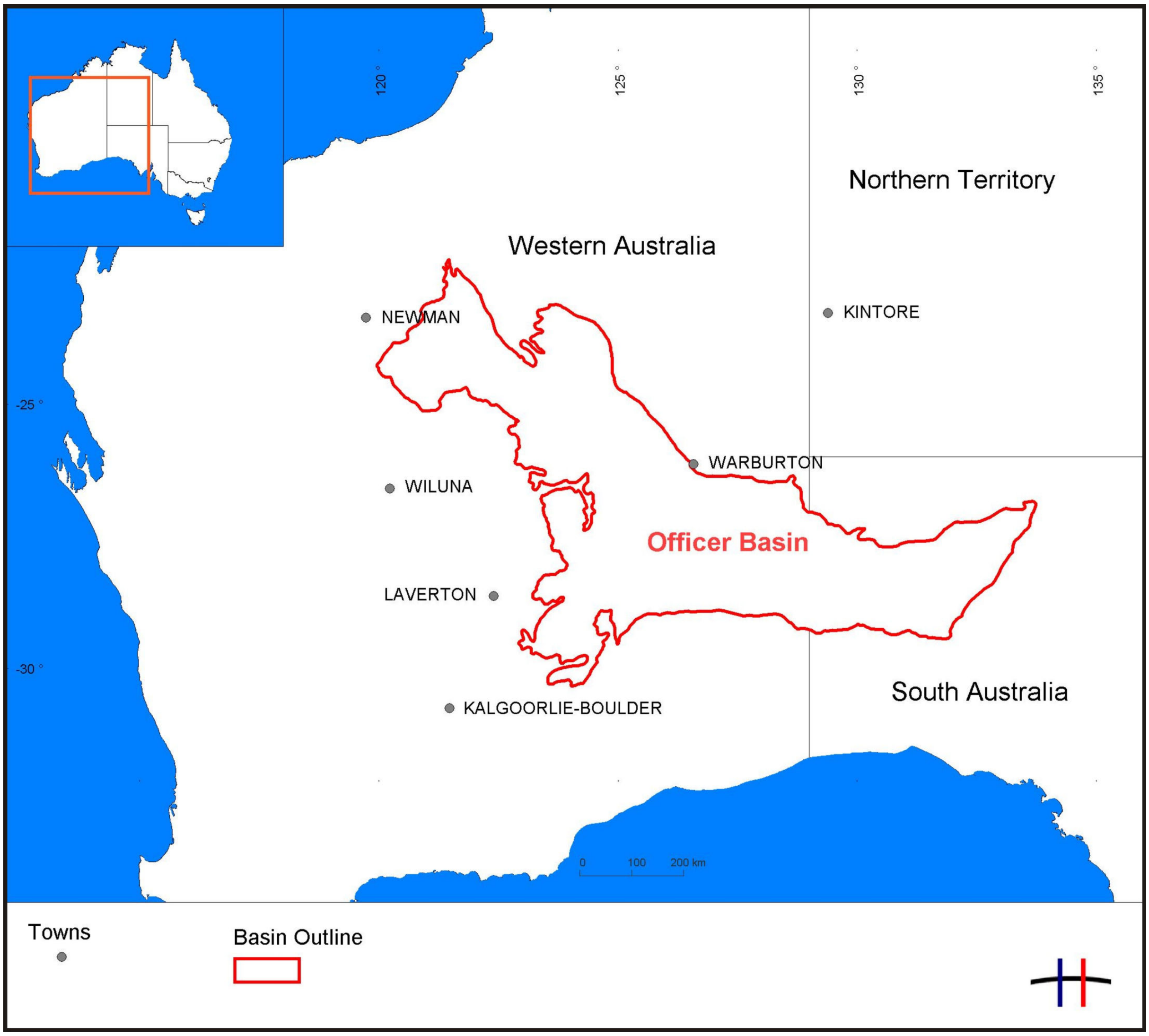

Figure 2: Location of the Officer Basin (basin polygon modified from Geoscience Australia database).

The Officer Basin is a large, episutural intracratonic basin. It is the southernmost and westernmost of the Centralian Superbasin, a series of Neoproterozoic basins including the Amadeus, Ngalia and Georgina basins (Walter et al., 1995). Sedimentation within the Officer Basin commenced with initiation of a foreland basin against an emergent Musgrave Complex. The main tectonic phase occurred during the Areyonga Movement—approximately 750 Ma—which has been identified as the central Australian response to breakup of Rodinia and separation of Laurentia from Gondwana (Baillie *et al.,* 1994; Apak and Moors, 2000).

2.1. Tectonic Framework

The Western Officer Basin is largely overlain by the Palaeozoic to Mesozoic Gunbarrel Basin (Figure 3) The Table Hill Volcanics are regarded as the basal sequence of the Gunbarrel Basin. For the purposes of this report, all references to the Western Officer Basin include the stratigraphic architecture of the Gunbarrel Basin.

A large extent of the southern portion of the Western Officer Basin extends beneath the Cainozoic Eucla Basin (Figure 3). The northern and north-eastern portion of the Officer Basin is bounded by the Paterson Orogen, Musgrave Complex and Canning Basin, whilst the western and north-western margins abut the Pilbara and Yilgarn cratons, and the Earaheedy and Collier basins.

The stratigraphic architecture of the Western Officer Basin is poorly constrained, since there is a paucity of geological and geophysical data. Whilst a series of seismic lines image the Yowalga area (Figure 3), elsewhere seismic data are sparse. Well control in the Western Officer Basin is limited to just 33 petroleum and stratigraphic wells—plus a number of shallow minerals bores—many of which are less than 500 m deep (Figure 3).

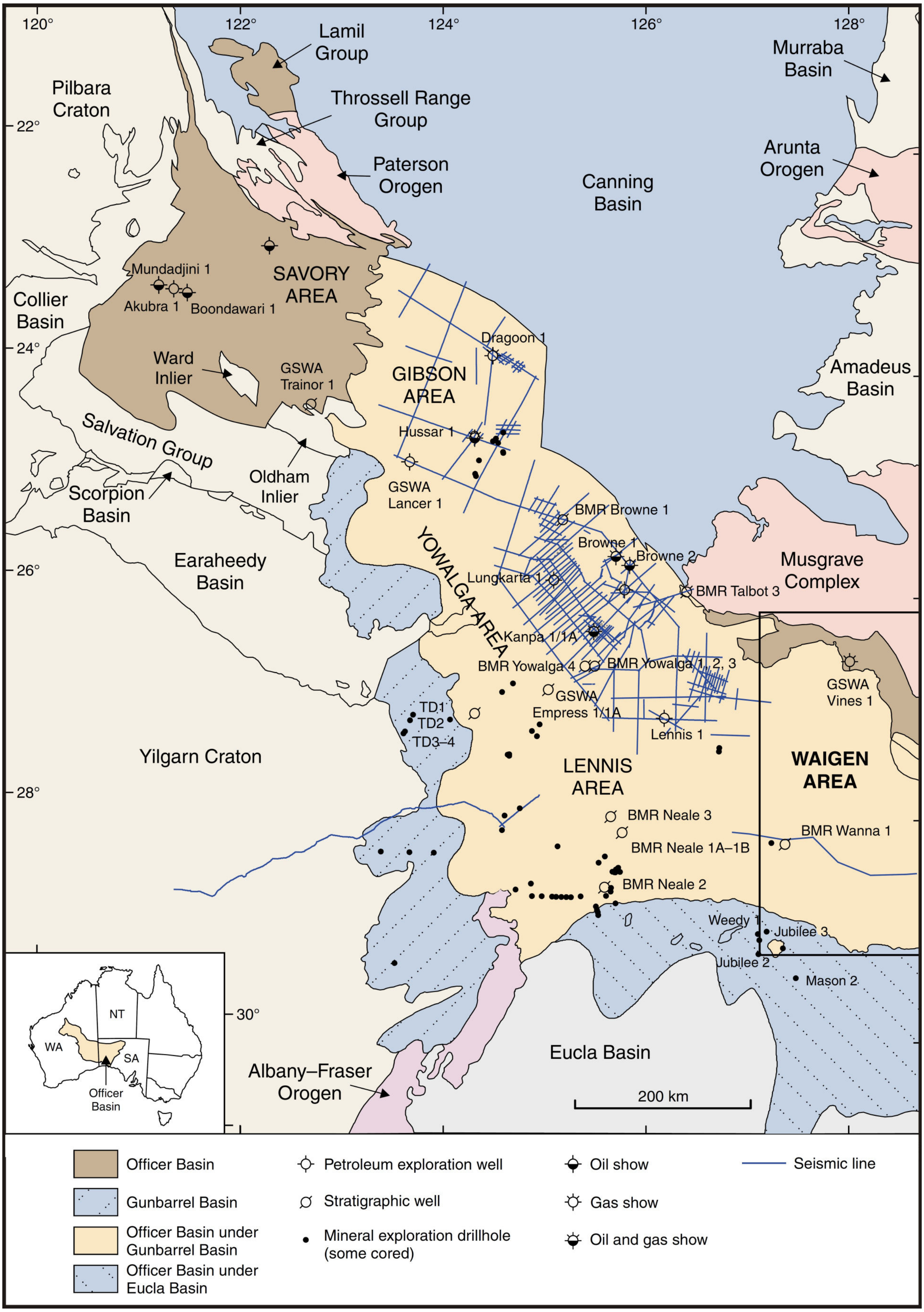

Figure 3: Regional tectonic setting of the Western Officer Basin (from D'Ercole et al., 2005).

Data derived from the OZ SEEBASEv2 project (FrOG Tech, 2007) suggest the sedimentary sequences within the Western Officer Basin thicken markedly towards the southern margin of the Musgrave Complex, reaching a maximum thickness in excess of 6,000 m where a number of discrete asymmetric depocentres have been confirmed by data (Apak & Moors, 2000; Simeonova & Iasky, 2005). Each tectonic subdivision is currently referred to in a geographic sense; and five areas have been delineated and studied in detail: Savory (Grey et al., 2005), Gibson (Moors and Apak, 2002; Grey et al., 2005; Simeonova & Iasky, 2005), Yowalga (Apak and Moors, 2000; Grey et al., 2005; Simeonova & Iasky, 2005), Lennis (Grey et al., 2005; Simeonova & Iasky, 2005) and Waigan (D'Ercole et al., 2005; Grey et al., 2005).

The structural grain of the Western Officer Basin dominantly trends in a north-westerly direction, parallel to the structural fabric observed in the Paterson Orogen (Simeonova & Iasky, 2005). Structural complexity is increased as a result of salt mobilisation, with both vertical diapirism and lateral salt piercement into overlying strata.

DMP has produced two cross sections through the Western Officer Basin, as shown in Figures 4 and 5.

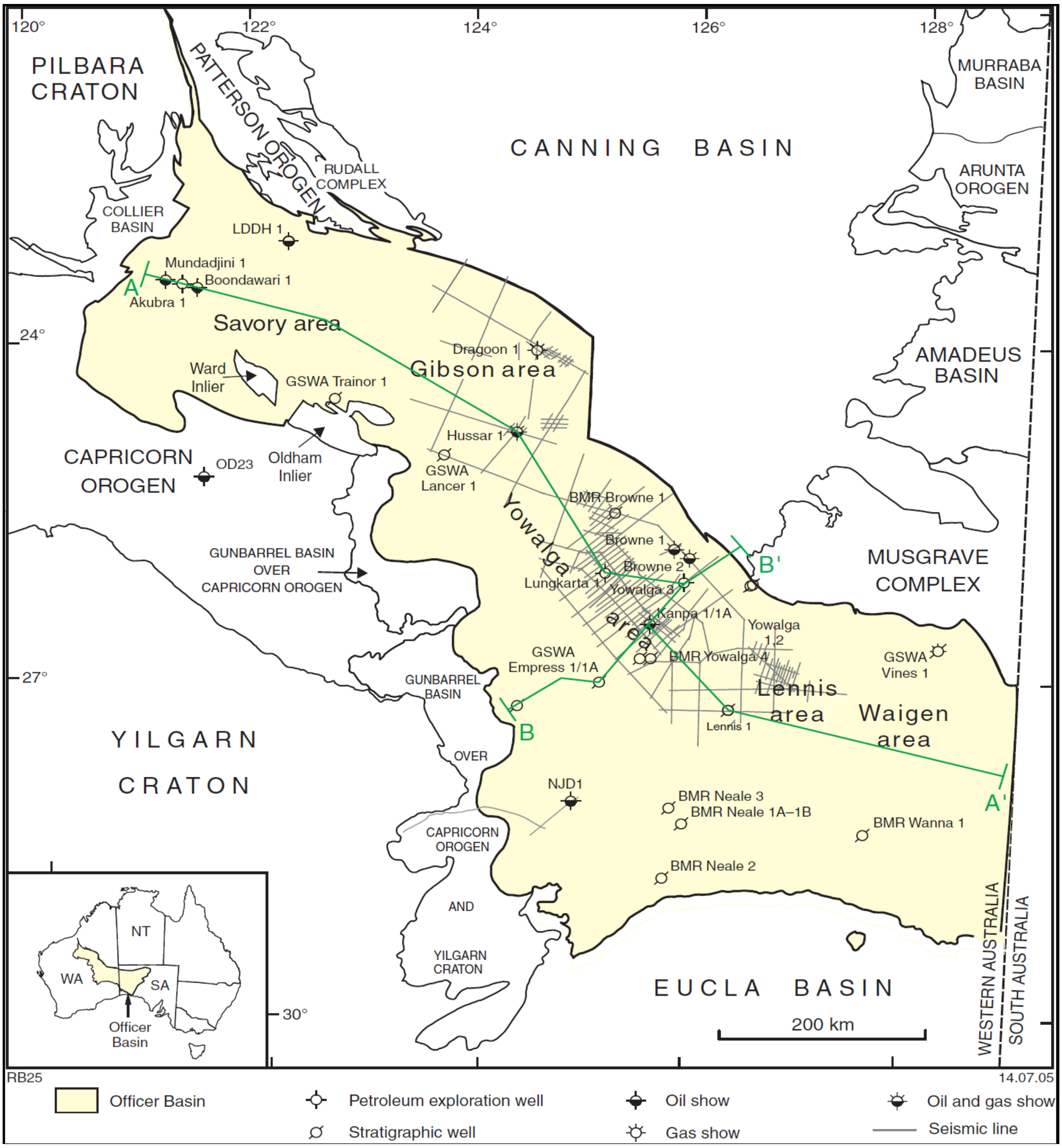

Figure 4: Green lines indicate the locations of the cross sections shown in Figure 5 (modified from Simeonova & Iasky, 2005).

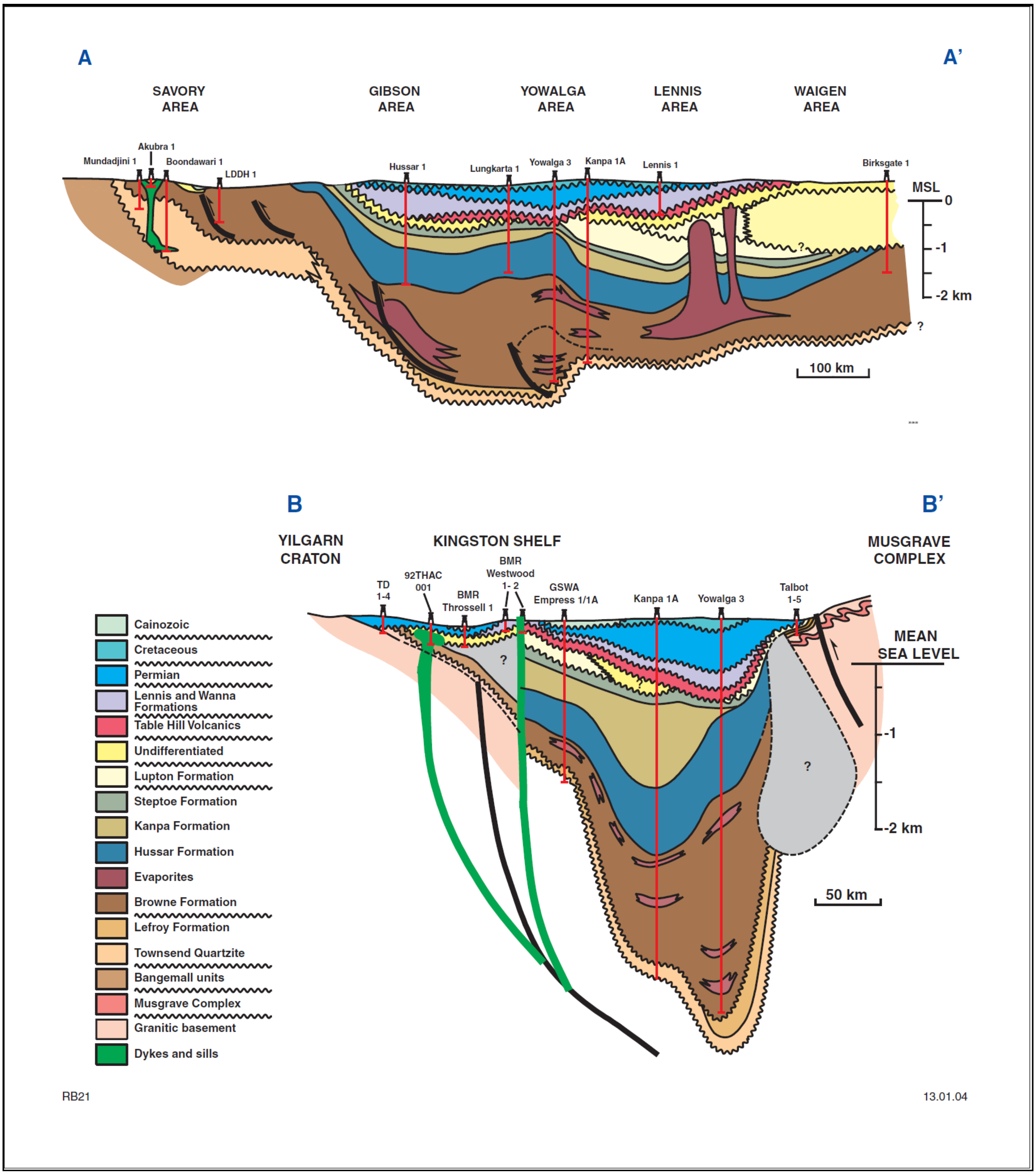

Figure 5: Cross sections through the Western Officer Basin. A–A’ parallel to structural grain; B–B’ perpendicular to the structural grain (modified from Stevens & Apak, 1999; GSWA, 1999.).

2.2. Stratigraphic Architecture

The regional stratigraphic architecture of the Western Officer Basin (Figure 6) is almost entirely derived from subsurface stratigraphic and petroleum datasets, as much of the basin is covered by a thin Cainozoic veneer. The various formations and stratigraphic units were described by D'Ercole et al., (2005); Simeonova and Iasky, (2005); and Grey et al., (2005).

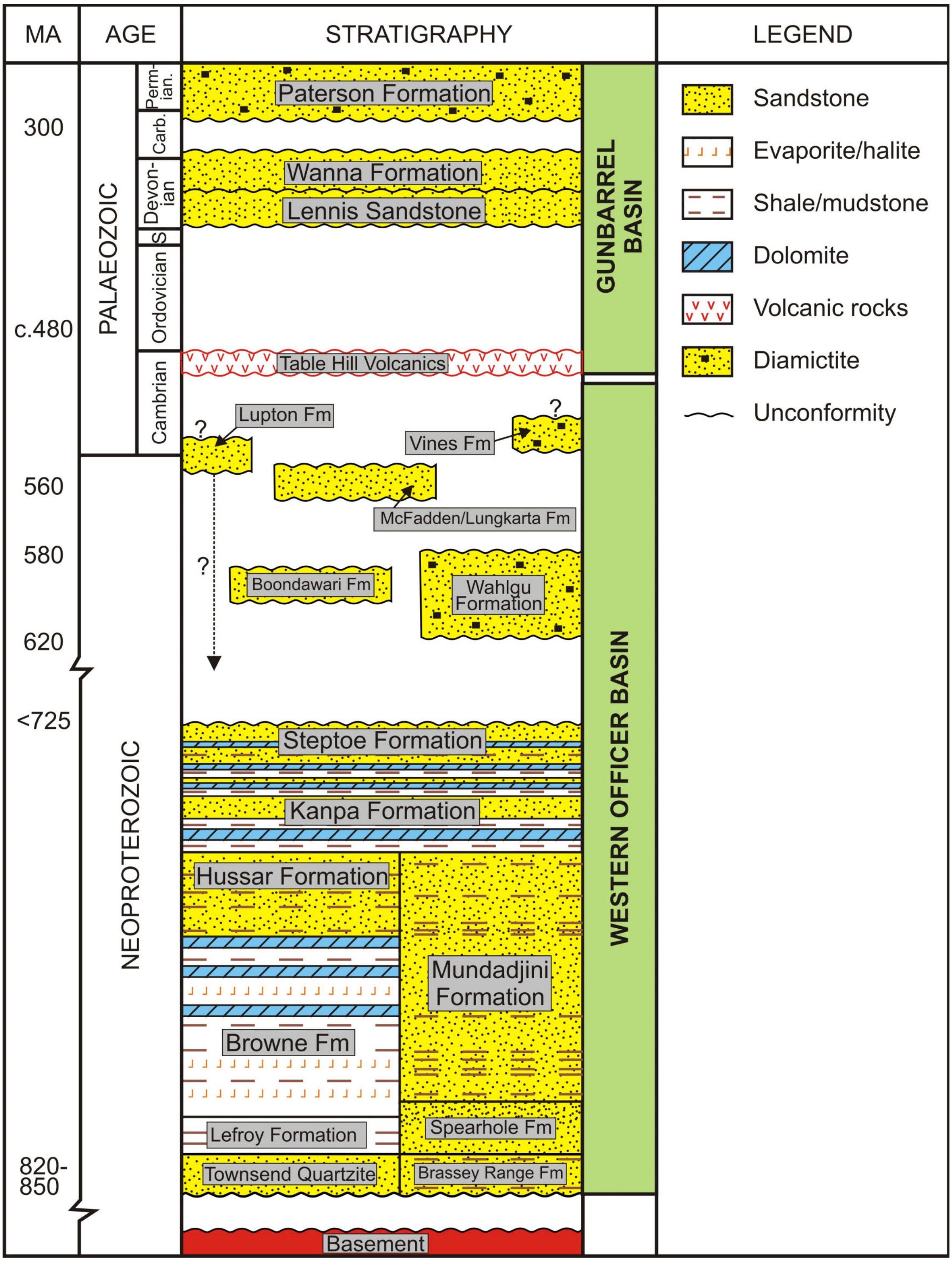

Figure 6: Stratigraphy of the Western Officer Basin and overlying Gunbarrel Basin (modified from D'Ercole et al., 2005; Grey et al., 2005). The Mundadjini Formation through to Brassey Range Formation is spatially restricted to the Savory area.

3. Basement Investigations

This section provides information for the following topics:-

For the 16 wells to be assessed:-

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

3.1. Basement depth

Recorded actual basement intercepts in the Western Officer Basin (Attachment C) were assessed in conjunction with the OZ SEEBASEv2 database (FrOG Tech, 2007) to determine depth-to-basement[1] for the 16 wells. These data are detailed in Attachment D and shown on Figure 7. The actual basement intercepts recorded in wells were given greater weighting over the OZ SEEBASEv2 dataset.

All available data suggest that Neoproterozoic basement reaches a maximum depth in excess of 6,000 m in parts of the Western Officer Basin.

3.2. Basement lithology

Predictions of basement lithology are listed in Attachment D and shown on Figure 8. 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 Western Officer Basin remains poorly constrained due to the small number of current basement intercepts.

[1] Rounded to the nearest 250 m.

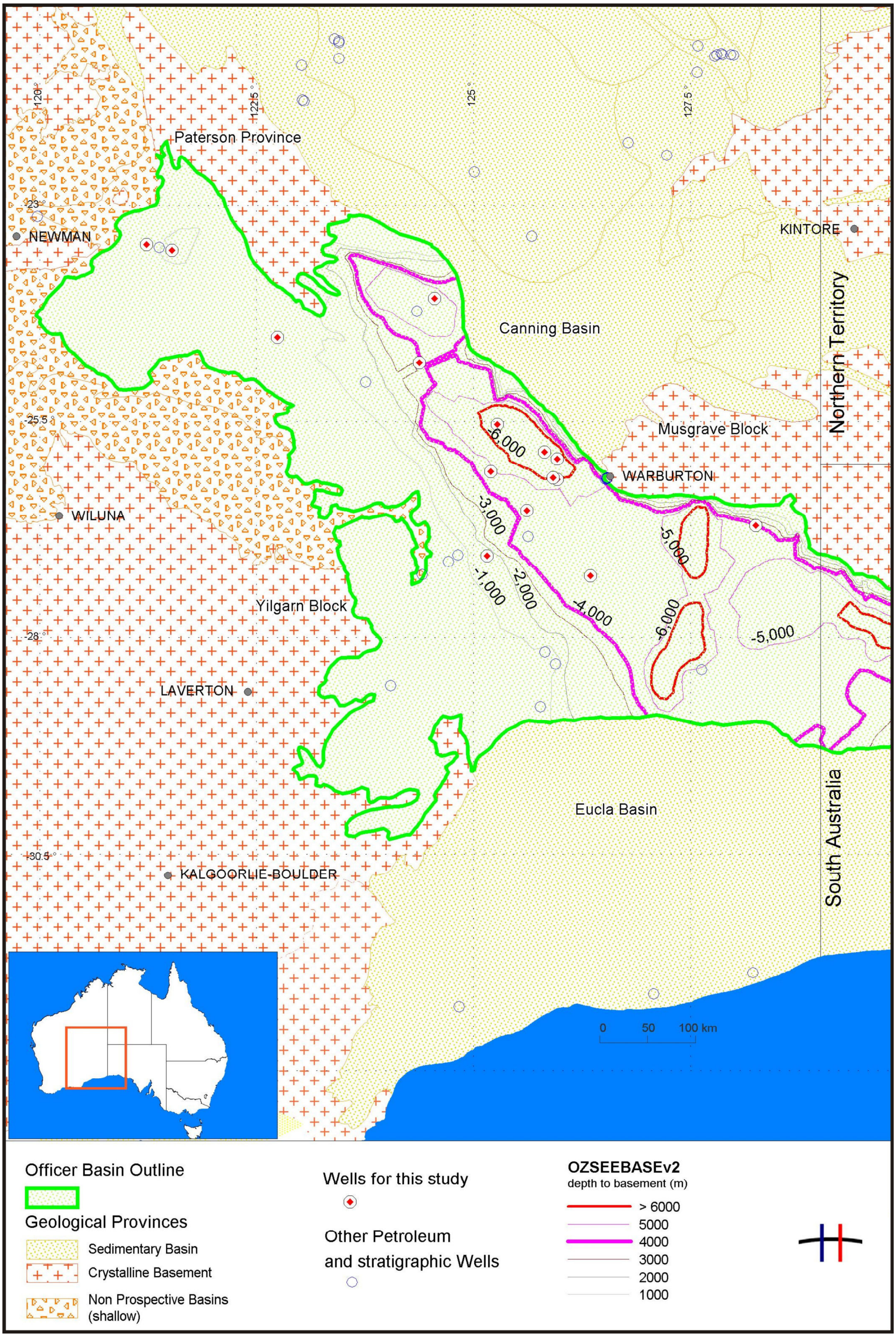

Figure 7: Depth to Basement contours for the Western Officer Basin. Data are from OZ SEEBASEv2 (FrOG Tech, 2007). Basin thickness is estimated to exceed 6,000 m in several north-westerly trending depocentres.

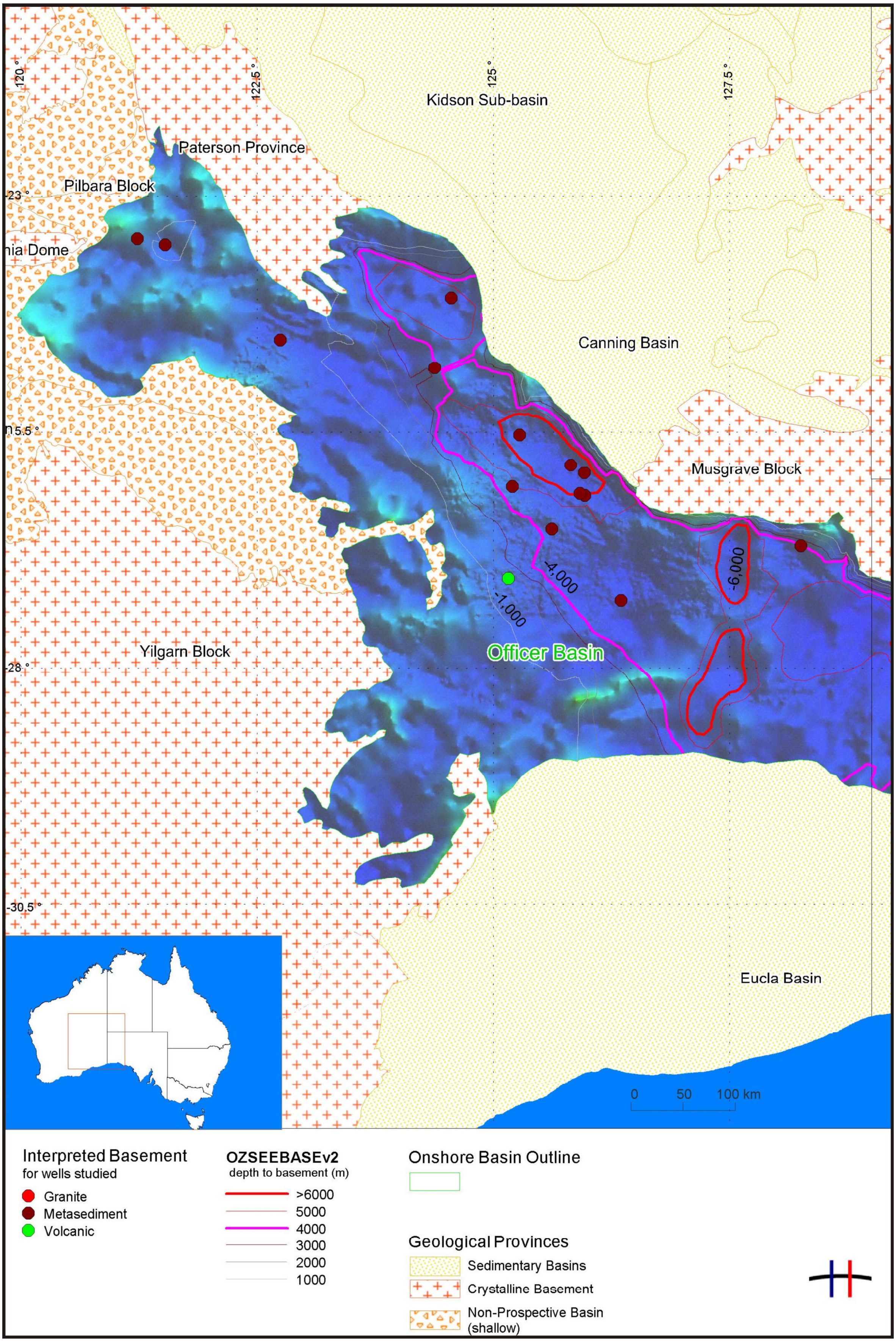

Figure 8: Predicted basement lithology in the Western Officer Basin beneath petroleum and stratigraphic wells listed in Attachment A. A gravity image of the basin provides the backdrop.

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 wells in the Western Officer Basin based on existing temperature data. HDR used its proprietary 1D heat flow modelling software to build heat flow models for each well for which adequate data were available. 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. 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 14 wells in the Western Officer 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. Temperatures recorded during drill stem tests (DSTs) were also accepted as accurate representations of virgin rock temperature, and used in the thermal models. 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 Western Officer Basin (Carnegie, Warburton and Giles weather stations). 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.

4.5. Temperature data issues

HDR checked the well temperature compilation provided by the DMP against primary data in well completion reports and identified several issues with the compilation. Firstly, whilst BHT temperatures were recorded, other temperature datasets such DSTs and formation tests were not always recorded. These data are invaluable for constraining the temperature regime in a well. In addition, there were a number of instances where the temperature at which mud fluid properties were measured had been recorded as being a BHT. 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. HDR recommends DMP undertake a quality control exercise of its well temperature database to ensure all relevant temperature data are captured, and to mitigate any erroneous inputs.

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 40 representative samples from lithologies of the Western Officer 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 E.

The majority of the samples from the deeper units of the Officer Basin were collected from Empress 1A. It is debatable as to how representative these lithologies are of the wider Western Officer Basin.

The 40 measurements of thermal conductivity included a number of measurements on 'pure' lithological samples such as 'shale', 'sandstone', etc. Where formation descriptions in well logs indicated mixed lithologies, a conductivity value for these formations was estimated from the weighted harmonic mean of the conductivities of the ‘pure’ lithological components. This process is described in Beardsmore and Cull (2001) and a summary of the calculation inputs is provided in Attachment F.

Some formations, such as the Browne Formation, have complex internal architecture since the environment of deposition was particularly dynamic (Figure 9). Given the sparse well data within the Western Officer Basin, and the limited number of samples tested, the thermal conductivity data should be viewed as preliminary only.

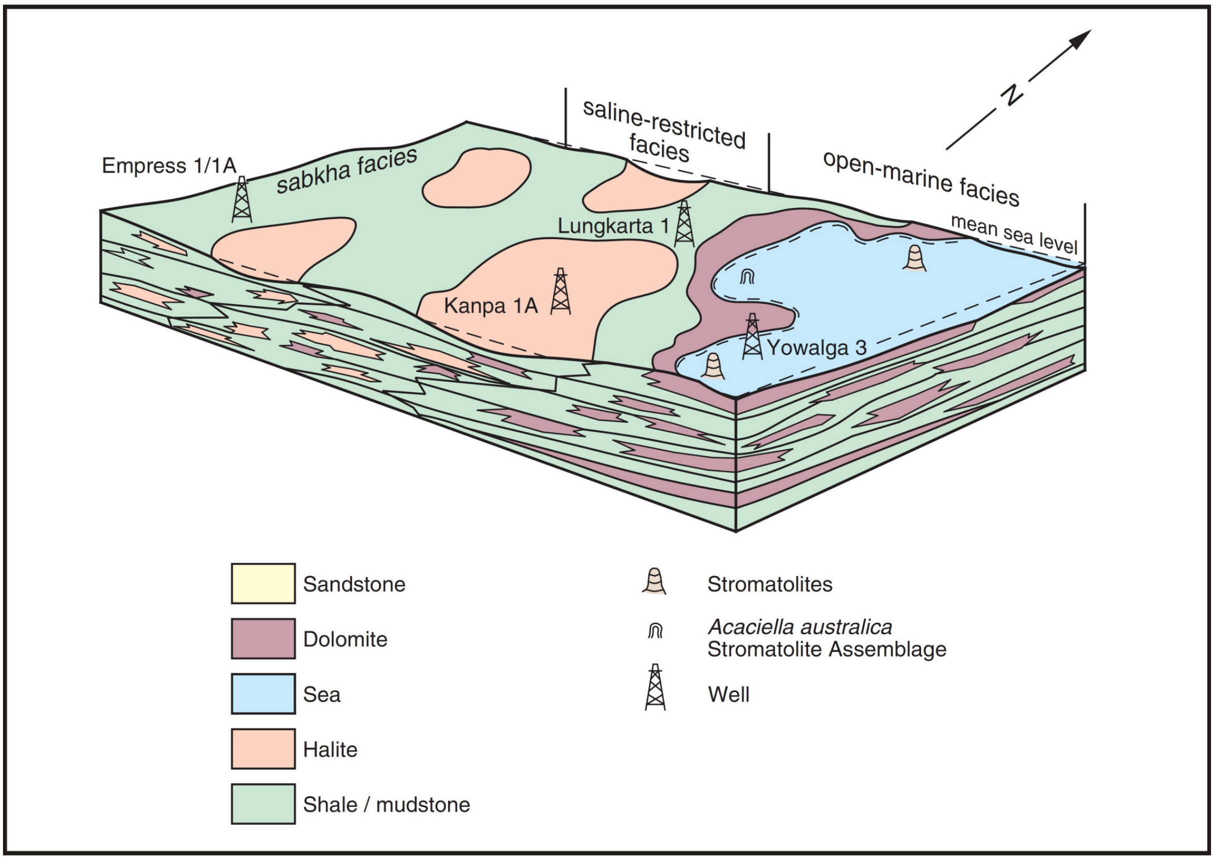

Figure 9: Depositional environment for the Browne Formation (modified from Apak and Moors, 2000)

Thermal conductivity values for each Western Officer Basin formation, as derived using the methods described above and used in the 1D heat flow models, are shown in Table 1.

Table 1: Thermal conductivities, once lithology mixing methods had been applied, by formation for the Western Officer Basin, as used for 1D heat flow modelling in this report (Appendix 2 of this report).

Formation	Conductivity (W/mK)	Uncertainty ±(W/mK)
Alluvium	1.42	0.14
Bejah Claystone	1.33	0.01
Samuel Formation	1.28	0.04
Paterson Formation	2.58	0.08
Wanna Formation	2.60	0.08
Lennis Sandstone	2.56	0.14
Table Hill Volcanics (basalt)	1.57	0.02
Table Hill Volcanics (dolerite)	2.25	0.07
unnamed sandstone	2.44	0.05
Vines Formation	2.69	0.11
Lupton Formation	-	-
McFadden Formation	2.47	0.36
Wahlgu Formation	2.69	0.11
Steptoe Formation	2.76	0.19
Kanpa Formation	2.89	0.40
Hussar Formation	2.99	0.28
Browne Formation	2.64	0.10
Lefroy Formation	1.61	0.04
Townsend Quartzite	4.45	0.30
Mundadjini Formation	3.80	0.11
Spearhole Formation	3.54	0.08
Brassey Range Formation	4.45	0.30
Cornelia Sandstone	3.50	0.70
Basement (basalt)	2.30	0.05
Basement (silty shale)	3.50	1.50

4.7. 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 inconsistencies when cross-referenced with the well completion reports. HDR recommends that the DMP consider a quality control exercise with regards to the Western Officer Basin formation tops database.

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 D) 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 sedimentary 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.

A special case was the Lefroy Formation. The Lefroy Formation is regarded as a deep water equivalent of the Townsend Quartzite (Apak & Moors, 2000). Only Empress 1A has intersected the formation, and the total thickness was just 19 m. HDR thus decided not to include the Lefroy Formation in modelling below TD in other wells since we had no confidence in its lateral extent nor thickness.

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

4.8. 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 Western Officer 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 Western Officer Basin, data from the Musgrave, Pilbara and Yilgarn regions were utilised as proxies, assuming that similar rocks may partly comprise the basement of the Western Officer Basin. Heat generation (μW/m^3) was estimated using an assumed rock density and the isotopic abundance method as described in Beardsmore and Cull (2001). Individual results for basalt and metasedimentary rocks are listed in Attachments G and H respectively.

Median heat generation results for basalt and metasedimentary rock samples adjacent to the Western Officer Basin are shown in Table 2. The data suggest that the heat generating potential of basalts and metasedimentary rocks around the Western Officer Basin is not high.

Table 2: Summary of heat generation estimates for two rock types around the Western Officer Basin.

Lithology	Number of samples	Assumed density (g/cm^3)	Heat generation (μW/m^3) Range	Heat generation (μW/m^3) Median
Basalt	23	3.00	0.44-1.10	0.73
Metasedimentary	9	2.48	0.23-1.65	0.66

The median values are based on a relatively small number of samples, and may change with further geochemical sampling of basement rocks beneath the Western Officer Basin.

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

5. Heat flow modelling

5.1. Estimated heat flow

The possibility of heat flow modelling was assessed for all 16 wells in the study. Two wells were found to have insufficient temperature data or inadequate formation top data to allow modelling of heat flow.

HDR incorporated temperature data, rock thermal conductivity data and heat generating potential estimates to model heat flow in each of the remaining 14 wells Data were incorporated into the model and heat flow was adjusted until the predicted temperature profile best fit the reported temperature datasets. HDR constructed 1D conductive heat flow models (Figure 10) for the 14 wells in the Western Officer 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 I.

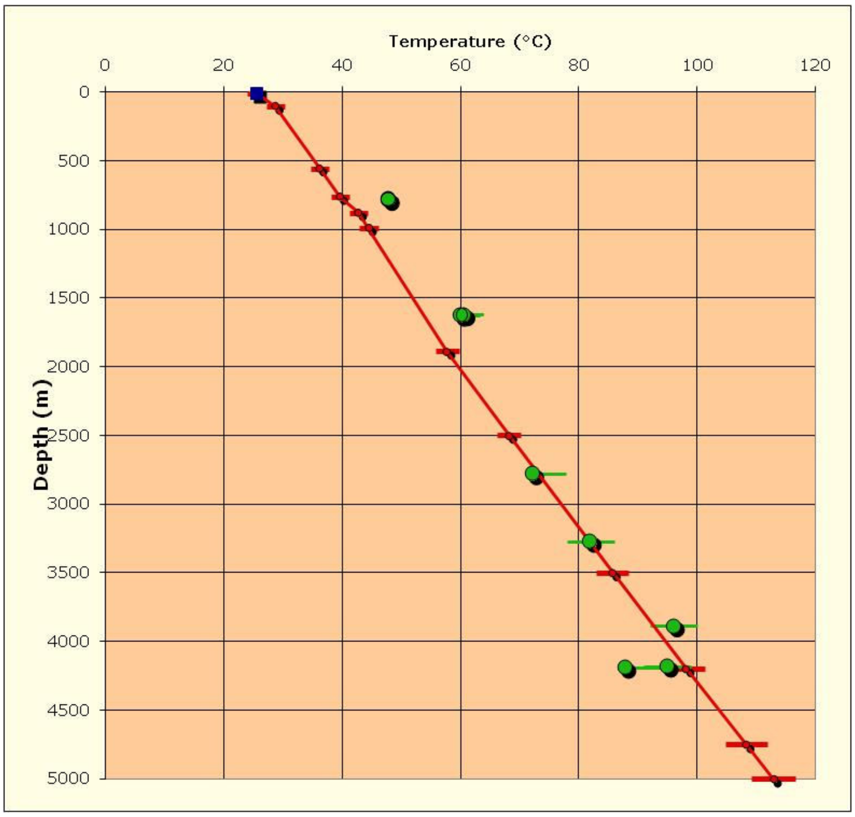

Figure 10: 1D heat flow model for the Yowlaga-3 petroleum well. The green circles represent individual temperature data; the green lines represent the degree of uncertainty; the red line is the predicted temperature profile for a heat flow of 42 ± 2.4 mW/m^2

Modelled heat flow for the Western Officer Basin ranges from 33 to 95 mW/m^2, with a median value of 52 mW/m^2. However, the distribution of just 14 data points over the entire Western Officer Basin makes it impossible to draw any firm conclusions about the true distribution of heat flow across the region.

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 I).

Table 3: Reliability ranking scheme for the 14 wells modelled in the Western Officer 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

Of the 14 wells modelled in this study, 10 were ascribed a reliability ranking of 1 or 2.

In order to ensure robustness of ensuing modelling, HDR usually excludes wells with a reliability ranking of 1 or 2 from assessments of the spatial and magnitude distribution of heat flow (Section 5.3) and temperature projections (Section 6).

However, given that 10 of the 14 wells modelled in this study have been ascribed a reliability ranking of 1 or 2, it was felt necessary in this instance to include all data.

5.3. Spatial and magnitude distribution of heat flow data

The spatial distribution of heat flow models is illustrated in Figure 11.

There is a paucity of data across large swathes of the Western Officer Basin, which is not surprising considering the limited number of well intersections. This lack of data renders impossible a thorough geothermal prospectivity assessment. In graphical representations of the data (Figures 11 to 15) areas greater than 75 km from the nearest data point appear blank. In addition, the heat flow estimate for petroleum well Yowalga-2 was significantly higher than the nearby wells Yowlga-1 and Yowalga-3, and was therefore excluded from the gridding process.

In general, those parts of the Western Officer Basin for which data exist suggest decreasing surface heat flow towards the centre of the basin. The lowest heat flow (<60 mW/m^2) is centred in the eastern Gibson, Yowalga and northern Lennis areas. Areas of higher heat flow occur on the margins of the basin, most notably the Savory area and Waigan area, although the elevated heat flow in the Savory area is possibly an artefact of the gridding process.

The most likely explanation for the lack of high heat flow is the lack of a significant heat source in the crust. Old cratonic areas are generally depleted in radioactive isotopes of uranium, thorium and potassium, and thus generate little internal heat.

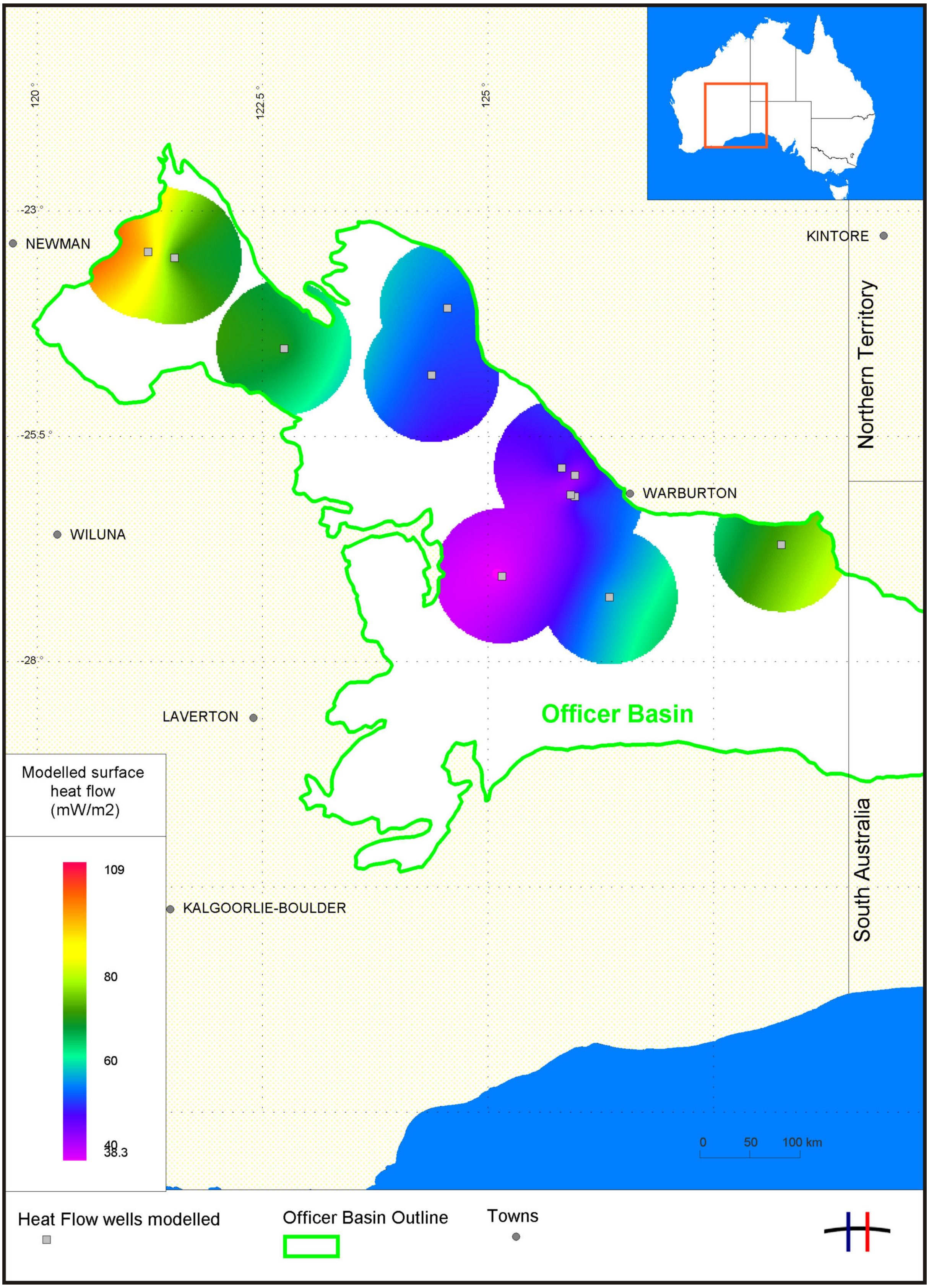

Figure 11: Gridded heat flow values for the Western Officer Basin. Each well was assumed to represent an area encompassing a radius of 75 km from the well. Those parts of the basin in which there are no wells have been left blank. Apparent elevated heat flow in the Savory area is probably an artefact of the gridding process.

6. Temperature projection

6.1. Depth to isotherms

Heat flow modelling allows the estimation of isotherm depths by applying Equation 1 (Section 4.2). HDR was commissioned to estimate depths to the 100°C, 150°C and 200°C isotherms and a compilation of these depths beneath each well is shown in Attachment J. The estimated formation that may be intersected at the isotherm depth, as determined in the process described in Section 4.7, is also shown in Attachment J.

The gridded 100°C, 150°C and 200°C isothermal surfaces are shown in Figures 12 to 14.

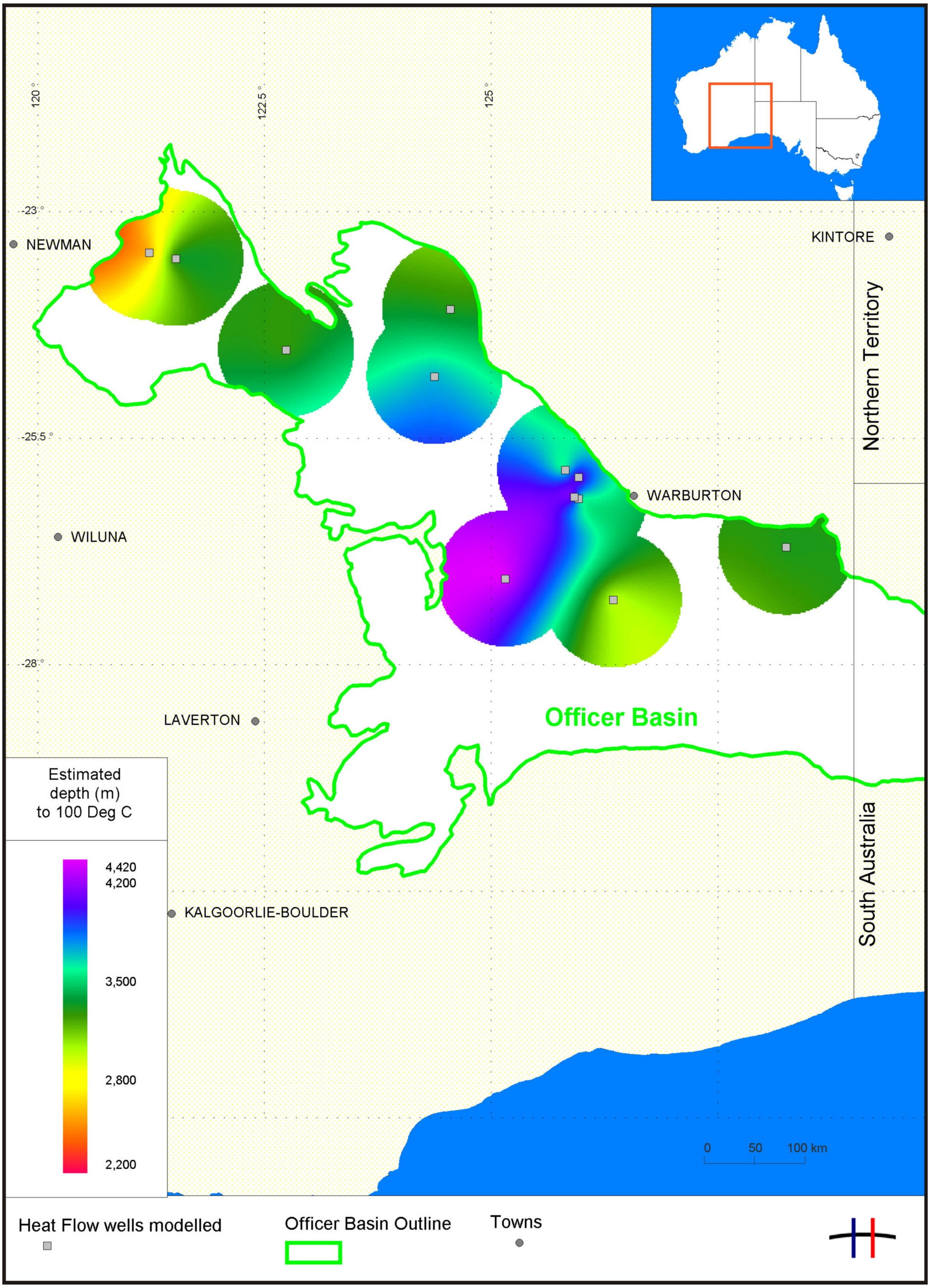

Figure 12: Estimated depth to the 100°C isotherm for the Western Officer Basin. Each well was assumed to represent an area encompassing a radius of 75 km from the well. Those parts of the basin in which there are no wells have been left blank.

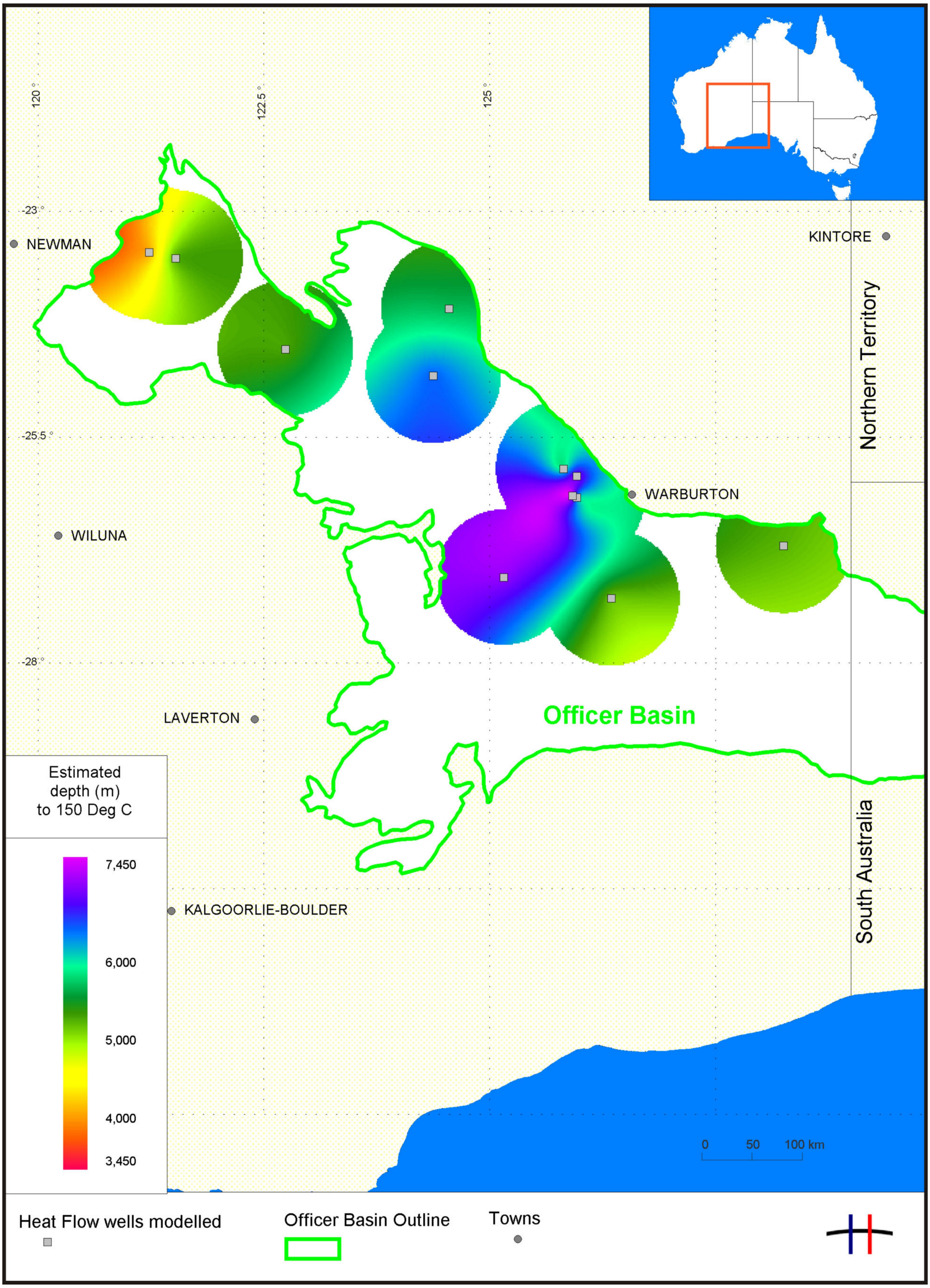

Figure 13: Estimated depth to the 150°C isotherm for the Western Officer Basin. Each well was assumed to represent an area encompassing a radius of 75 km from the well. Those parts of the basin in which there are no wells have been left blank.

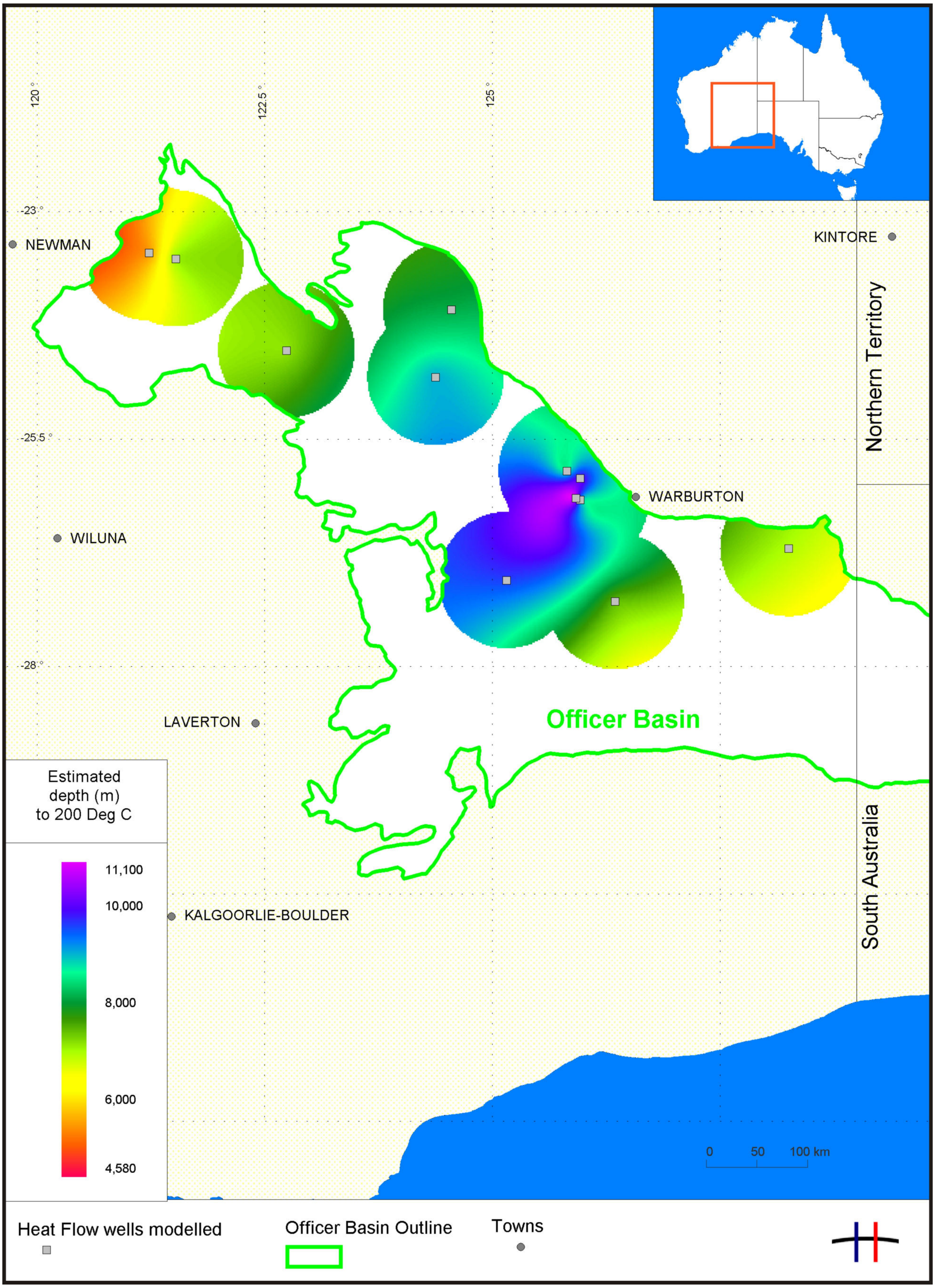

Figure 14: Estimated depth to the 200°C isotherm for the Western Officer Basin. Each well was assumed to represent an area encompassing a radius of 75 km from the well. Those parts of the basin in which there are no wells have been left blank.

6.2. Temperature at basement

HDR was commissioned to estimate the temperature at the top of the basement from 1D heat flow modelling. Following consultation with the DMP, HDR restricted this request to areas where basement is <5,000 m deep, an assumed economic drilling limit under current conditions.

Figure 15 shows the modelled temperature at 5,000 m depth for the Western Officer Basin and results beneath each well are tabulated in Attachment J.

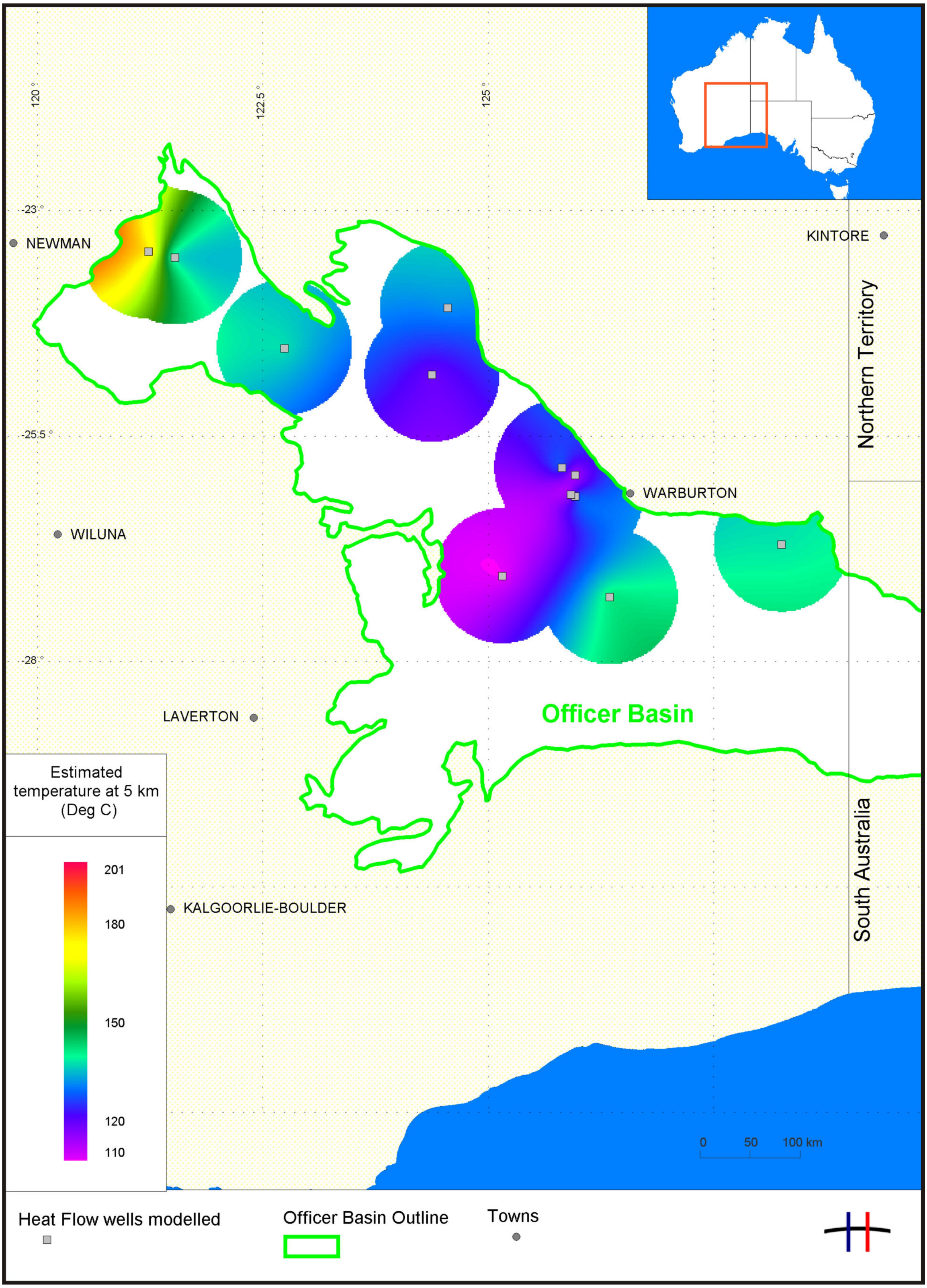

Figure 15: Estimated temperature at 5,000 m depth for the Western Officer Basin. Each well was assumed to represent an area encompassing a radius of 75 km from the well. Those parts of the basin in which there are no wells have been left blank.

7. Stress field in the Western Officer Basin

The successful development of an EGS is dependent upon several factors, but one of the most critical factors is the response of the fractured rock mass to the *in-situ* stress field. Stress-dependant permeability of deep-seated, fractured rocks is well documented in studies relating to both hydrocarbon and geothermal reservoirs, as well as nuclear waste repositories (e.g. Gentier *et al*., 2000; Hillis *et al*., 1997; Hudson *et al*., 2005). In particular, *in-situ* stress fields are known to exert a significant control on fluid flow patterns in fractured rocks with a low matrix permeability. For example, in a key study of deep (>1,700 m) boreholes, Barton *et al*. (1995) found that permeability manifests itself as fluid flow focussed along fractures favourably aligned within the *in-situ* stress field, and that if fractures are critically stressed this can impart a significant anisotropy to the permeability of a fractured rock mass. Preferential flow occurs along fractures that are oriented orthogonal to the minimum principal stress direction (due to low normal stress), or inclined ~30° to the maximum principal stress direction (due to dilation).

Knowledge of both the local- and regional-scale stress regime is important in order to understand the effects of stress-dependent fracture permeability and, in EGS operations, potential reservoir growth and flooding directions under hydraulic stimulation. In general, stress fields are anisotropic and inhomogeneous. They are defined in simplified terms by three mutually orthogonal principal axes of stress, being the maximum (S_1), intermediate (S_2) and minimum (S_3) stress axes. In practice, the classification of far-field stress regimes is based upon the Andersonian scheme, which relates the three major styles of faulting in the crust to the three major arrangements of the principal axes of stress i.e. the vertical principal stress (S_V) and the maximum and minimum horizontal principal stresses (S_H and S_h, respectively) (Anderson, 1951). These three major styles of faulting are: (a) normal faulting where $S_V > S_H > S_h$; (b) strike-slip faulting where $S_H > S_V > S_h$; and (c) reverse (or thrust) faulting where $S_H > S_h > S_V$ (Figure 16).

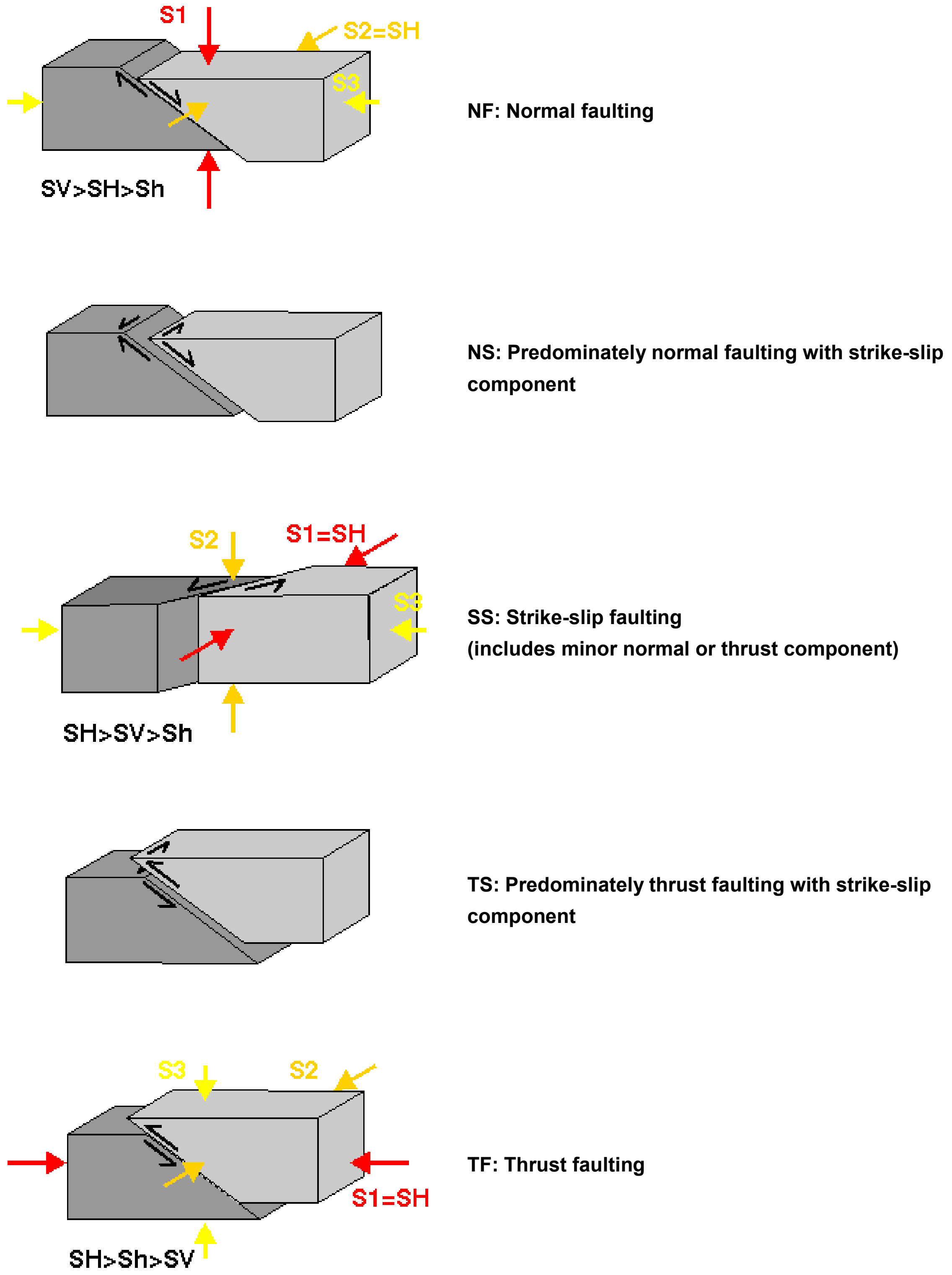

Figure 16: The World Stress Map stress regime classifications (NF, NS, SS, TS, TF) and their associated styles of faulting (from Heidbach et al., 2008).

The determination of the local stress field is important as theory predicts enhanced permeability associated with critically stressed faults or fractures that are either undergoing dilation (~parallel to S_1) or shear reactivation (<45° to S_1) under the influence of the contemporary stress field.

With respect to EGS developments, knowledge of the stress field and pre-existing fractured rock mass can be used to make preliminary predictions of fracture and reservoir growth directions during hydraulic stimulation. The three major fracture growth directions are:

(a) Steep to vertical dipping fractures that strike orthogonal to S_h in a normal faulting stress regime ($S_V>S_H>S_h$);

(b) Steep to vertical dipping fractures that strike <45° (commonly 30°) to the direction S_H in a strike-slip faulting stress regime ($S_H>S_V>S_h$), and;

(c) Shallow to horizontal dipping fractures (aligned in the direction of S_H) that strike ~parallel to S_h in a thrust faulting stress regime ($S_H>S_h>S_V$).

7.1. Western Officer Basin stress measurement data

The World Stress Map reports only one *in situ* stress indicator within the Western Officer Basin, from the petroleum well Kanpa-1A. Kanpa-1A contained several borehole breakouts that collectively indicate that the maximum horizontal stress direction (S_H) in this region is approximately east-west (~100°). The relative magnitudes are currently unknown (Heidbach et al., 2008).

8. Prospectivity

Nearly all the modelled areas within the Western Officer Basin have the 150°C isotherm modelled at greater than 5,000 m depth, as shown in Figure 15. In addition, most modelled areas have the 150°C isotherm apparently coincident with Mesoproterozoic basement which is highly unlikely to preserve any natural permeability.

The modelled temperature at 5,000 m depth are not particularly encouraging for geothermal potential and it should once again be noted the readings in the western Savory area shown in Figure 15 are likely to be an artefact of the gridding process.

The paucity of data and the unresolved stress regime means that no conclusions can be drawn in regards to the potential effects of the local *in situ* stress field on EGS developments. Resolving this issue will require that the local stress field be determined at a number of individual well locations.

9. Conclusions and Recommendations

Data from the 14 wells modelled in this study suggest that the Western Officer Basin has a median heat flow value of 52 mW/m^2. This is lower than the mean of 58.3 mW/m^2 as recorded for Proterozoic basins by Pollack et al., (1993) and considerably lower than other Western Australian basins (HDRPL, 2008; Driscoll et al., 2009).

The lack of relevant geophysical and geological datasets means that a definitive geothermal assessment of the Western Officer Basin is currently unachievable. Only 33 petroleum and stratigraphic wells have been drilled in the Western Officer Basin—an area of approximately 300,000 km^2.

Those parts of the Western Officer Basin for which data exist suggest decreasing surface heat flow towards the centre of the basin with the lowest heat flow (<60 mW/m^2) being centred in the eastern Gibson, Yowalga and northern Lennis areas. Areas of higher heat flow are apparent on the margins of the basin, most notably the Savory area and Waigan area. However, apparent elevated heat flow in the Savory area is probably an artefact of the gridding process. The most likely explanation for the low heat flow is a lack of a significant heat source in the crust.

Nearly all heat flow models in the Western Officer Basin predict the 150°C isotherm at greater than 5,000 m depth, implying limited potential EGS prospectivity given current economic drilling limitations. In addition, most models predict the 150°C isotherm coincident with Mesoproterozoic basement, which is highly unlikely to preserve any natural permeability, thus negating the potential for Hot Sedimentary Aquifer (HSA) geothermal systems.

In regards to the contemporary, *in-situ* stress field of the Western Officer Basin, a lack of regional-scale stress indicator data and the unresolved stress regime means that no conclusions can be drawn in regards to the potential effects of the local *in situ* stress field on EGS developments.

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 Western Officer Basin.
- DMP should contact all minerals and petroleum companies that have leases in the Western Officer 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.
- DMP should further investigate the heat generation potential of basement rocks.
- DMP should consider a field program to obtain stress field estimates via hydraulic fracturing or borehole imaging of existing wells. With robust stress field data, 2D or 3D numerical hydro-mechanical modelling could be undertaken to constrain expected geothermal reservoir growth and flooding directions. Such a modelling exercise would also require: (1) estimates of pore fluid pressures from either well drill stem (DST) or leak off (LOT) tests; (2) laboratory estimates of the hydraulic and bulk moduli properties of key rock types as collected from selected core samples; and (3) detailed structural interpretations at both the regional and prospect scale.

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Attachment A: Wells in the Western Officer 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 (°)
BMR Browne 1	Yowalga Area	W002125	Stratigraphic	121.9	N	Permian	Paterson Formation	GDA94	-25.5330656	125.2763596
Boondawari 1	Blake Sub-basin	W002178	Stratigraphic	1367	N	Cambrian	Table Hill Volcanics	GDA94	-23.5182138	121.5219006
Browne 1	Yowalga Area	W000123	Stratigraphic	387	N	Neoproterozoic	Browne Formation	GDA94	-25.8500242	125.8160139
Browne 2	Yowalga Area	W000124	Stratigraphic	292.6	N	Permian	Paterson Formation	GDA94	-25.9319519	125.9638598
Dragoon 1	Gibson Area	W001183	Stratigraphic	2000	N	Neoproterozoic	Browne Formation	GDA94	-24.0790210	124.5508082
GSWA Empress 1A	Westwood Shelf	W002146	Stratigraphic	1624.6	N	Mesoproterozoic	Basement	GDA94	-27.0523250	125.1581306
GSWA Trainor 1	Trainor Platform	W002034	Stratigraphic	709	N	Mesoproterozoic	Cornelia Formation	GDA94	-24.5255306	122.7411333
GSWA Vines 1	Waigen Area	W002375	Stratigraphic	2017.5	N	Cambrian/Neoproterozoic	Vines Formation	GDA94	-26.7013528	128.2521444
Hussar 1[1]	Westwood Shelf	W001197	Stratigraphic	2040	Y[1]	Neoproterozoic	Browne Formation	GDA94	-24.8192811	124.3774355
Kanpa 1A	Yowalga Area	W001209	Petroleum	3803	N	Neoproterozoic	Townsend Quartzite	GDA94	-26.5268662	125.6157158
Lennis 1	Yowalga Area	W000125	Stratigraphic	615	N	Cambrian	Table Hill Volcanics	GDA94	-27.2833000	126.3500000
Lungkarta 1	Yowalga Area	W001381	Petroleum	1770	N	Neoproterozoic	Hussar Formation	GDA94	-26.0773284	125.1974616
Mundadjini 1	Blake Sub-basin	W002166	Stratigraphic	600	N	Neoproterozoic	Spearhole Formation	GDA94	-23.4537552	121.2311356
Yowalga 1	Yowalga Area	W000126	Stratigraphic	613	N	Devonian	Lennis Sandstone	GDA94	-26.1700000	125.9667000
Yowalga 2	Yowalga Area	W000145	Petroleum	989.4	N	Cambrian	Kanpa Formation	GDA94	-26.1700000	125.9666667
Yowalga 3	Yowalga Area	W001053	Petroleum	4196.5	N	Neoproterozoic	Browne Formation	GDA94	-26.1494881	125.9169417

[1] Deviated between 4° and 6.5° interval 1,200-2,037 m; however, this has a negligible effect on true vertical depth.

Attachment B: Wells in the Western Officer Basin not part of this study.

Well Name	Sub-basin	Well ID	Well Status	Total Depth (m)	Deviated well?	Age at Total Depth	Datum	Latitude (°)	Longitude (°)
Akubra 1	Blake Sub-basin	W002179	Stratigraphic	181	N	Proterozoic	GDA94	-23.4889983	121.3782175
BMR Madley 1	Gibson Sub-basin	W002128	Stratigraphic	207.6	N	unknown	GDA94	-24.2264033	124.3485674
BMR Neale 1A - 1B	Neale Arch	W002129	Stratigraphic	205.75	N	Proterozoic	GDA94	-28.3036328	125.9447204
BMR Neale 2	Jubilee Shelf	W002303	Stratigraphic	74.8	N	Permian	GDA94	-28.7953389	125.7713934
BMR Neale 3	Neale Arch	W002134	Stratigraphic	38.1	N	Permian	GDA94	-28.1653000	125.8213864
BMR Talbot 1	Yowalga Sub-basin	W002306	Stratigraphic	33.06	N	Proterozoic	GDA94	-26.1519149	126.5430594
BMR Talbot 2	Yowalga Sub-basin	W002307	Stratigraphic	13.7	N	Tertiary	GDA94	-26.1553111	126.5402595
BMR Talbot 3	Yowalga Sub-basin	W002308	Stratigraphic	77.36	N	Proterozoic	GDA94	-26.1592112	126.5369596
BMR Talbot 4	Yowalga Sub-basin	W002309	Stratigraphic	69.6	N	Precambrian	GDA94	-26.1625151	126.5330596
BMR Talbot 5	Yowalga Sub-basin	W002131	Stratigraphic	95.1	N	Precambrian	GDA94	-26.1652819	126.5180264
BMR Throssell 1	Westwood Shelf	W002126	Stratigraphic	198.12	N	Cambrian	GDA94	-27.2719746	124.4097187
BMR Wanna 1	Jubilee Shelf	W002132	Stratigraphic	154.53	N	Permian	GDA94	-28.3663958	127.6302621
BMR Warri 20	Gibson Sub-basin	W002133	Stratigraphic	265.48	N	Proterozoic	GDA94	-24.0819562	124.5513426
BMR Westwood 1	Westwood Shelf	W001990	Stratigraphic	85.34	N	Proterozoic	GDA94	-27.0436355	124.8197129
BMR Westwood 2	Westwood Shelf	W002127	Stratigraphic	101.5	N	Proterozoic	GDA94	-27.1208594	124.7113814
BMR Yowalga 4	Yowalga Sub-basin	W002311	Stratigraphic	42.97	N	Permian	GDA94	-26.8330262	125.6271722
GSWA Lancer 1	Westwood Shelf	W002643	Stratigraphic	1501.3	N	Mesoproterozoic	GDA94	-25.0456944	123.7555833

Attachment C: Basement lithology and depths for all wells in the Western Officer Basin that intersected basement.

Well Name	Datum	Latitude (°)	Longitude (°)	TD (m)	Basement type	Depth to Basement (m)	Notes
BMR Rason 1	GDA94	-28.5540000	123.7950000	68.5	granite [adamellite]	44	
BMR Rason 2	GDA94	-28.5540000	124.0460000	146.59	quartz-feldspar-biotite migmatite	144	
BMR Rason 3	GDA94	-28.5540000	123.4980000	74.7	granite	31	
GSWA Empress 1A	GDA94	-27.0523250	125.1581306	1624.6	mudstone and siltstone [very dense and heat affected, dark grey, thinly laminated]	1540.2	
GSWA Lancer 1	GDA94	-25.0456944	123.7555833	1501.3	sandstone [bluish-grey, pebbly, clayey, medium-grained cross-bedded]	1478.9	Mesoproterozoic Cornelia Formation
GSWA Trainor 1	GDA94	-24.5255306	122.7411333	709	mudstone and siltstone [moderate developed schistosity, fault zones, slickensides]	83.1	Mesoproterozoic Cornelia Formation

Attachment D: Estimated basement lithology and depths for all Western Officer Basin wells in this study.

Well Name	Well ID	Total Depth (m)	Probable Basement Lithology	Basement Depth (m)	Depth to Basement Beneath Total Depth (m)	Datum	Latitude (°)	Longitude (°)
BMR Browne 1	W002125	121.9	Metasediment	6500	6378.1	GDA94	-25.533066	125.276360
Boondawari 1	W002178	1367	Metasediment	1400	33	GDA94	-23.518214	121.521901
Browne 1	W000123	387	Metasediment	6500	6113	GDA94	-25.850024	125.816014
Browne 2	W000124	292.6	Metasediment	6500	6207.4	GDA94	-25.931952	125.963860
Dragoon 1	W001183	2000	Metasediment	5000	3000	GDA94	-24.079021	124.550808
GSWA Empress 1A	W002146	1624.6	Basalt	1540	-84.6	GDA94	-27.052325	125.158131
GSWA Trainor 1	W002034	709	Metasediment	800	91	GDA94	-24.525531	122.741133
GSWA Vines 1	W002375	2017.5	Metasediment	4500	2482.5	GDA94	-26.701353	128.252144
Hussar 1	W001197	2040	Metasediment	3750	1710	GDA94	-24.819281	124.377436
Kanpa 1A	W001209	3803	Metasediment	4500	697	GDA94	-26.526866	125.615716
Lennis 1	W000125	615	Metasediment	4500	3885	GDA94	-27.283300	126.350000
Lungkarta 1	W001381	1770	Metasediment	4750	2980	GDA94	-26.077328	125.197462
Mundadjini 1	W002166	600	Metasediment	800	200	GDA94	-23.453755	121.231136
Yowalga 1	W000126	613	Metasediment	6000	5387	GDA94	-26.170000	125.966700
Yowalga 2	W000145	989.4	Metasediment	6000	5010.6	GDA94	-26.170000	125.966667
Yowalga 3	W001053	4196.5	Metasediment	6000	1803.5	GDA94	-26.149488	125.916942

Attachment E: Summary of measured rock thermal conductivity data for the Western Officer Basin (Appendix 2 of this report).

Sample	Well	Depth from (m)	Depth to (m)	Depth from (')	Depth to (')	Conductivity (W/mK)	Uncertainty ± (W/mK)	Formation	Lithology
DIR150	Yowalga 2			2796'	2796' 9"	2.56	0.18	Kanpa Formation	reddish finely laminated interbedded slt/sst; thick quartz veins
DIR151	Yowalga 2			3242'	3242' 9"	2.93	0.24	Kanpa Formation	cream to light grey finely laminated interbedded slt/sst
DIR168	GSWA Empress 1A	165.9	166.1			2.56	0.14	Lennis Sandstone	partially friable yellow medium-grained sst
DIR169	GSWA Empress 1A	127.05	127.2			2.19	0.10	Paterson Formation	buff to tan medium-grained sst
DIR170	GSWA Empress 1A	116.15	116.4			3.27	0.07	Paterson Formation	light grey coarse-grained to granule matrix supported pebble cgl tillite
DIR171	GSWA Empress 1A	294.25	294.6			2.49	0.05	unnamed Sandstone	reddish brown medium-grained sst
DIR172	GSWA Empress 1A	106.7	107			2.44	0.05	Paterson Formation	light grey slt tillite, pebble sized granodiorite clast
DIR173	GSWA Empress 1A	284.7	284.9			1.57	0.02	Table Hill Volcanics	reddish grey basalt
DIR174	GSWA Empress 1A	367.8	368			2.26	0.07	Wahlgu Formation	red slt/cst with mottled grey patches
DIR175	GSWA Empress 1A	351.8	352			3.05	0.05	Wahlgu Formation	red medium-grained sst with occasional granule-small pebble float
DIR176	GSWA Empress 1A	431.5	431.7			1.55	0.21	Wahlgu Formation	red/light grey cst chips
DIR177	GSWA Empress 1A	504.65	504.85			4.61	0.23	Steptoe Formation	grey dolomite, some stylolites
DIR178	GSWA Empress 1A	603.8	604			1.43	0.16	Steptoe Formation	grey cst chips
DIR179	GSWA Empress 1A	568.3	568.5			2.96	0.12	Steptoe Formation	red/grey fine- to medium-grained sst
DIR180	GSWA Empress 1A	651.4	651.7			4.02	0.25	Kanpa Formation	grey dolomite with wavy laminations (soft sediment deformation?) and thick stylolite seams
DIR181	GSWA Empress 1A	743.5	743.8			3.02	0.99	Kanpa Formation	light grey sst
DIR182	GSWA Empress 1A	805.9	806.1			2.41	0.34	Kanpa Formation	dark grey mst
DIR183	GSWA Empress 1A	931	931.3			4.18	0.19	Hussar Formation	red/brick red laminated slt/fine-grained sst
DIR184	GSWA Empress 1A	1122.1	1122.4			4.24	0.25	Hussar Formation	brick red medium- to coarse-grained sst; granules pick out cross beds

DIR185	GSWA Empress 1A	1091.1	1091.3			1.78	0.36	Hussar Formation	light grey/dark grey laminated mst/cst; red mottled patches
DIR186	GSWA Empress 1A	1075.9	1076.2			5.54	0.11	Hussar Formation	grey dolomite with soft sediment deformation and calcite filed fractures; vuggy in part
DIR187	GSWA Empress 1A	1223.3	1223.55			2.18	0.06	Hussar Formation	brick red mst/cst; grey mottled patches
DIR188	GSWA Empress 1A	1309.65	1309.8			5.25	0.37	Browne Formation	brick red to opaque halite
DIR189	GSWA Empress 1A	1409.4	1409.55			2.68	0.12	Browne Formation	brick red cst with mottled grey patches; halite crystals in the matrix?
DIR190	GSWA Empress 1A	1403.75	1403.95			2.09	0.06	Browne Formation	red cst with mottled grey patches (thin bands of opaque halite but not in the tested intervals)
DIR191	GSWA Empress 1A	1531.7	1531.9			1.61	0.04	Lefroy Formation	heavily fractured maroon to grey slt
DIR192	GSWA Empress 1A	1603.6	1603.8			2.30	0.05	Basement	Mesoproterozoic basement (basalt)
DIR193	GSWA Empress 1A	1558.9	1559.2			2.05	0.05	Basement	Mesoproterozoic basement (dark grey/black finely laminated silty shale)
DIR194	Boondawari 1	302.2	302.4			4.45	0.09	Mundadjini Formation	red/brick red fine-grained sst
DIR195	Boondawari 1	613.3	613.5			1.43	0.04	Spearhole Formation	brick red slt
DIR196	Boondawari 1	612.35	612.6			4.81	0.09	Spearhole Formation	red coarse-grained to granular sst
DIR197	Boondawari 1	1365.4	1365.6			2.25	0.07	Table Hill Volcanics	light grey dolerite
DIR198	Boondawari 1	834.6	834.8			4.45	0.30	Brassey Range Formation	red medium-grained to granular sst
DIR199	Boondawari 1	349.6	349.8			2.17	0.08	Spearhole Formation	brick red cst/slt with grey/greenish mottling patches (clasts/reducing spots?)
DIR200	BMR Browne 1			30' 11"	31' 7"	1.33	0.01	Bejah Claystone	salmon pink to cream cst with frequent pink-purple mottling; very light and almost porcelaneous
DIR201	BMR Browne 1			325'	325' 6"	1.30	0.04	Samuel Formation	dark grey to yellow-grey laminated cst, slt and fine-grained sst; sulphurous, occasional bioturbation, micaceous, glauconite?

DIR202	BMR Browne 1			192' 1"	192' 7"	1.25	0.03	Samuel Formation	reddish-brown to ochre slt, cst with finely laminated interbeds of whispy fine-grained sst
DIR203	BMR Neale 1A-1B			369' 11"	369' 11"	2.60	0.08	Wanna Formation	tan fine-grained sst; occasional reddish brown mottling; feint cross-bedding
DIR204	BMR Neale 1A-1B			327'	327' 7"	2.87	0.57	McFadden Formation	grey to tan/grey fine-grained sst
DIR205	BMR Neale 1A-1B			308'	308' 9"	1.59	0.05	McFadden Formation	brick red slt
DIR206	BMR Throssell 1			200'	200' 10"	-	-	Kanpa Formation	grey cst with abundant gypsum crystal; chicken-wire appearance?

Attachment F: Formation conductivities for the western Officer 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	Alluvium not tested; value taken from Beardsmore, 2005
Bejah Claystone	1.33	0.01	Value based on DIR200
Samuel Formation	1.28	0.04	Value calculated from DIR201 [50% of the representative lithology] and DIR202 [50% of the representative lithology]
Paterson Formation	2.58	0.08	Value calculated from DIR169 [33.3% of the representative lithology], DIR170 [33.3% of the representative lithology] and DIR172 [33.3% of the representative lithology]
Wanna Formation	2.60	0.08	Value based on DIR203
Lennis Sandstone	2.56	0.14	Value based on DIR168
Table Hill Volcanics (basalt)	1.57	0.02	Value based on DIR173
Table Hill Volcanics (dolerite)	2.25	0.07	Value based on DIR197
unnamed sandstone	2.44	0.05	Value based on DIR171
Vines Formation	2.69	0.11	Vines Formation not tested; TC based on Beardsmore & Cull 2001 Table 4.2
Lupton Formation	-	-	Lupton Formation not tested; the formation possibly not penetrated by the wells
McFadden Formation	2.47	0.36	Value calculated from DIR204 [80% of the representative lithology] and DIR205 [20% of the representative lithology]
Wahlgu Formation	2.69	0.11	Value calculated from DIR174 [10% of the representative lithology], DIR175 [80% of the representative lithology] and DIR176 [10% of the representative lithology]
Steptoe Formation	2.76	0.19	Value calculated from DIR177 [40% of the representative lithology], DIR178 [20% of the representative lithology] and DIR179 [40% of the representative lithology]
Kanpa Formation	2.89	0.40	Value calculated from DIR150 [20% of the representative lithology], DIR151 [20% of the representative lithology], DIR180 [20% of the representative lithology], DIR181 [20% of the representative lithology] and DIR182 [20% of the representative lithology]
Hussar Formation	2.99	0.28	Value calculated from DIR183 [20% of the representative lithology], DIR184 [20% of the representative lithology], DIR185 [20% of the representative lithology], DIR186 [20% of the representative lithology] and DIR187 [20% of the representative lithology]
Browne Formation	2.64	0.10	Value calculated from DIR188 [20% of the representative lithology], DIR189 [40% of the representative lithology] and DIR190 [40% of the representative lithology]
Lefroy Formation	1.61	0.04	Value based on DIR191
Townsend Quartzite	4.45	0.30	Townsend Quartzite not tested; TC based on Brassey Range Formation DIR198

Mundadjini Formation	3.80	0.11	Value calculated from DIR194 [70% of the representative lithology], DIR180 Kanpa Fm [15% of the representative lithology] and DIR187 Hussar Fm [15% of the representative lithology]
Spearhole Formation	3.54	0.08	Value calculated from DIR195 [10% of the representative lithology], DIR196 [80% of the representative lithology] and DIR199 [10% of the representative lithology]
Brassey Range Formation	4.45	0.30	Value based on DIR198
Cornelia Sandstone	3.50	0.70	Cornelia Sandstone not tested. TC based on HDR experience with Mesoproterozoic indurated slt/sst.
Basement (basalt)	2.30	0.05	Value based on DIR192
Basement (silty shale)	3.50	1.50	Value based on DIR193 and HDR experience with metasedimentary basement

Attachment G: Estimated heat generation for basalt samples adjacent to the Western Officer 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 (μW/m^3)
Yilgarn Region	-	-26.16233	124.452294	GDA94	basalt	basalt (mafic extrusive)	0.95	7900	0.99	6	3	0.84
Yilgarn Region	Eastern Gold-fields Province	-28.68727	122.663784	GDA94	basalt	basalt (mafic extrusive)	0.154	1300	2.5	2	3	0.90
Yilgarn Region	Eastern Gold-fields Province	-28.68652	122.662456	GDA94	basalt	basalt (mafic extrusive)	0.114	900	1.2	4	3	0.67
Yilgarn Region	Eastern Gold-fields Province	-28.74409	122.515159	GDA94	basalt	basalt (mafic extrusive)	0.047	400	2.3	4	3	0.99
Yilgarn Region	Eastern Gold-fields Province	-28.74981	122.514805	GDA94	basalt	basalt (mafic extrusive)	0.148	1200	2.1	2	3	0.78
Yilgarn Region	Eastern Gold-fields Province	-28.79916	122.594811	GDA94	basalt	basalt (mafic extrusive)	0.04	300	1.8	1	3	0.60
Yilgarn Region	Eastern Gold-fields Province	-28.79448	122.597022	GDA94	basalt	basalt (mafic extrusive)	0.04	300	2.5	1	3	0.81
Yilgarn Region	Eastern Gold-fields Province	-28.79855	122.604528	GDA94	basalt	basalt (mafic extrusive)	0.047	400	1.8	1	3	0.61
Yilgarn Region	Eastern Gold-fields Province	-28.84681	122.882528	GDA94	basalt	basalt (mafic extrusive)	0.253	2100	2.1	5	3	1.03
Yilgarn Region	Eastern Gold-fields Province	-28.85114	122.873409	GDA94	basalt	basalt (mafic extrusive)	0.194	1600	0.9	2	3	0.44
Yilgarn Region	Eastern Gold-fields Province	-28.85294	122.873642	GDA94	basalt	basalt (mafic extrusive)	0.129	1100	1	5	3	0.70
Yilgarn Region	Eastern Gold-fields Province	-28.85429	122.872821	GDA94	basalt	basalt (mafic extrusive)	0.158	1300	2.1	2	3	0.78
Yilgarn Region	Eastern Gold-fields Province	-28.85523	122.870656	GDA94	basalt	basalt (mafic extrusive)	0.122	1000	1.3	3	3	0.62
Yilgarn Region	Eastern Gold-fields Province	-28.86115	122.86542	GDA94	basalt	basalt (mafic extrusive)	0.094	800	1	3	3	0.53
Yilgarn Region	Eastern Gold-fields Province	-28.86346	122.864627	GDA94	basalt	basalt (mafic extrusive)	0.104	900	1.3	2	3	0.54

Musgrave Region	Musgrave Block	-26.29582	128.401342	GDA94	basalt	amygdaloidal basalt (mafic extrusive)	0.84	7000	0.5	6	3	0.69
Musgrave Region	Musgrave Block	-26.19302	128.429041	GDA94	basalt	mafic extrusive	2	16600	1	8	3	1.10
Musgrave Region	Musgrave Block	-26.19302	128.429041	GDA94	basalt	amygdaloidal basalt (mafic extrusive)	1.61	13400	0.5	7	3	0.84
Musgrave Region	Musgrave Block	-26.29582	128.401342	GDA94	basalt	slightly amygdaloidal basalt (mafic extrusive)	1.34	11100	0.5	6	3	0.74
Musgrave Region	Musgrave Block	-26.23381	128.57634	GDA94	basalt	amygdaloidal basalt (mafic extrusive)	1.38	11500	1.5	4	3	0.87
Musgrave Region	Musgrave Block	-25.93881	128.551108	GDA94	basalt	metabasalt, amygdaloidal, massive, recrystallised (mafic extrusive)	0.19	1600	1	5	3	0.70
Yilgarn Region	Eastern Goldfields Province	-29.31881	122.531064	GDA94	basalt	fine-grained basalt with very poorly preserved pillows (mafic extrusive)	0.57	4700	1	5	3	0.73
Yilgarn Region	Eastern Goldfields Province	-28.80168	122.603656	GDA94	basalt	basalt - low-grade actinolite-epidote-rich (mafic extrusive)	0.24	2000	1	2	3	0.47

Median	**0.73**

Attachment H: Estimated heat generation for metasedimentary rock samples adjacent to the Western Officer 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 ($\mu W/m^3$)
Pilbara Region	Pilbara Block	-23.03022	122.68138	GDA94	sandstone	fine- to medium-grained sandstone	0.683	5700	0.72	4.4	2.48	0.51
Pilbara Region	-	-23.01621	122.658611	GDA94	sandstone	medium-grained sandstone	2.392	19900	0.77	4.6	2.48	0.66
Pilbara Region	-	-23.27524	123.280641	GDA94	sandstone	medium-grained sandstone	0.193	1600	0.37	1.9	2.48	0.23
Yilgarn Region	Eastern Goldfields Province	-28.72319	122.526362	GDA94	breccia	felsic volcanic (rhyolitic?) breccia, volcanic breccia, or sedimentary breccia	0.04	300	1.16	2	2.48	0.41
Musgrave Region	Musgrave Block	-26.29582	128.401342	GDA94	sandstone	feldspathic sandstone	4.56	37900	1	8	2.48	1.09
Musgrave Region	Musgrave Block	-26.01681	128.550338	GDA94	quartzite	SPH-OPX-CPX-PL quartzite	0.06	500	2.5	12	2.48	1.39
Musgrave Region	Musgrave Block	-26.29582	128.401342	GDA94	sandstone	feldspathic sandstone	4.73	39300	3.5	6	2.48	1.57
Musgrave Region	Musgrave Block	-25.9908	128.597337	GDA94	pelite	SI-GNT-KFS-QZ pelite	1.73	14400	2	16	2.48	1.65
Yilgarn Region	Eastern Goldfields Province	-29.3321	122.552623	GDA94	schist	epidote-actinolite schist, sequence clearly steeply dipping	0.11	900	0.5	2	2.48	0.26

Median	**0.66**

Attachment I: Modelled heat flow values and estimates of reliability for wells in the Western Officer 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)	uncer-tainty ± (mW/m^2)
BMR Browne 1	121.9	Metasediment	6500	6378.1	GDA94	-25.533066	125.276360	no temperature data				
Boondawari 1	1367.0	Metasediment	1400	33.0	GDA94	-23.518214	121.521901	n	n	2	73	1.8
Browne 1	387.0	Metasediment	6500	6113.0	GDA94	-25.850024	125.816014	n	n	2	50	1.2
Browne 2	292.6	Metasediment	6500	6207.4	GDA94	-25.931952	125.963860	n	n	2	42	1.0
Dragoon 1	2000.0	Metasediment	5000	3000.0	GDA94	-24.079021	124.550808	y	y	5	54	1.7
GSWA Empress 1A	1624.6	Basalt	1540	-84.6	GDA94	-27.052325	125.158131	n	n	2	38	1.1
GSWA Trainor 1	709.0	Metasediment	800	91.0	GDA94	-24.525531	122.741133	n	n	2	72	12.1
GSWA Vines 1	2017.5	Metasediment	4500	2482.5	GDA94	-26.701353	128.252144	n	n	2	75	12.1
Hussar 1	2040.0	Metasediment	3750	1710.0	GDA94	-24.819281	124.377436	n	y	3	52	2.7
Kanpa 1A[1]	3803.0	Metasediment	4500	697.0	GDA94	-26.526866	125.615716	n	y	3	33	0.9
Lennis 1	615.0	Metasediment	4500	3885.0	GDA94	-27.283300	126.350000	n	n	2	58	2.1
Lungkarta 1	1770.0	Metasediment	4750	2980.0	GDA94	-26.077328	125.197462	no temperature data				
Mundadjini 1	600.0	Metasediment	800	200.0	GDA94	-23.453755	121.231136	n	n	1	95	1.4
Yowalga 1	613.0	Metasediment	6000	5387.0	GDA94	-26.170000	125.966700	n	n	2	51	1.1
Yowalga 2	989.4	Metasediment	6000	5010.6	GDA94	-26.170000	125.966667	n	n	2	92	2.3
Yowalga 3	4196.5	Metasediment	6000	1803.5	GDA94	-26.149488	125.916942	n	y	4	42	1.0

[1]Whilst Kanpa 1A had several Horner Plots and BHT data, it should be noted that the 1D heat flow model was not a good fit through these data. Hence the reliability is recorded as 3 rather than 4.

Attachment J: Estimated isotherm depths and basement temperatures for wells in the Western Officer Basin.

Well Name	Total Depth (m)	Datum	Latitude (°)	Longitude (°)	Heat Flow (W/mK)	Uncer-tainty (W/mK)	Temp at 5,000 m (°C)	Depth to 100°C	Fm	Depth to 150°C	Fm	Depth to 200°C	Fm
BMR Browne 1	121.9	GDA94	-25.5330656	125.2763596	no temperature data								
Boondawari 1	1367	GDA94	-23.5182138	121.5219006	73	1.8	138.8	3419	Basement	5439	Basement	7324	Basement
Browne 1	387	GDA94	-25.8500242	125.8160139	50	1.2	131.3	3588	Browne Fm	5809	Browne Fm	8510	Basement
Browne 2	292.6	GDA94	-25.9319519	125.9638598	42	1.0	114.2	4228	Browne Fm	7225	Basement	10475	Basement
Dragoon 1	2000	GDA94	-24.0790210	124.5508082	54	1.7	134.5	3374	Browne Fm	5801	Basement	8298	Basement
GSWA Empress 1A	1625	GDA94	-27.0523250	125.1581306	38	1.1	109.6	4456	Basement	7279	Basement	10072	Basement
GSWA Trainor 1	709	GDA94	-24.5255306	122.7411333	72	12.1	140.2	3332	Basement	5391	Basement	7314	Basement
GSWA Vines 1	2018	GDA94	-26.7013528	128.2521444	75	12.1	140.4	3385	Vines Fm	5356	Basement	7136	Basement
Hussar 1	2040	GDA94	-24.8192811	124.3774355	52	2.7	121.4	3789	Basement	6588	Basement	9254	Basement
Kanpa 1A	3803	GDA94	-26.5268662	125.6157158	33	0.9	85.5	6368	Basement	11108	Basement	15949	Basement
Lennis 1	615	GDA94	-27.2833000	126.3500000	58	2.1	144.7	3036	Browne Fm	5253	Basement	7570	Basement
Lungkarta 1	1770	GDA94	-26.0773284	125.1974616	no temperature data								
Mundadjini 1	600	GDA94	-23.4537552	121.2311356	95	1.4	180.5	2582	Basement	4118	Basement	5544	Basement
Yowalga 1	613	GDA94	-26.1700000	125.9667000	51	1.1	132.9	3547	Browne Fm	5886	Basement	8505	Basement
Yowalga 2	989.4	GDA94	-26.1700000	125.9666667	92[1]	2.3	235.5	anomalous heat flow results					
Yowalga 3	4197	GDA94	-26.1494881	125.9169417	42	1.0	112.9	4296	Basement	7814	Basement	11701	Basement

[1]Apparent heat flow estimated from Yowlga-2 is anomalously higher than Yowalga-1 and -3. Since Yowalga-2 is rated 2 for temperature reliability, and it is in close proximity to the other two wells, it was decided to exclude Yowalga-2 from temperature projections.

Appendix 1

Heat flow models and temperature data used for each well in the Officer Basin Report DMP0260909

HDR

July 2010

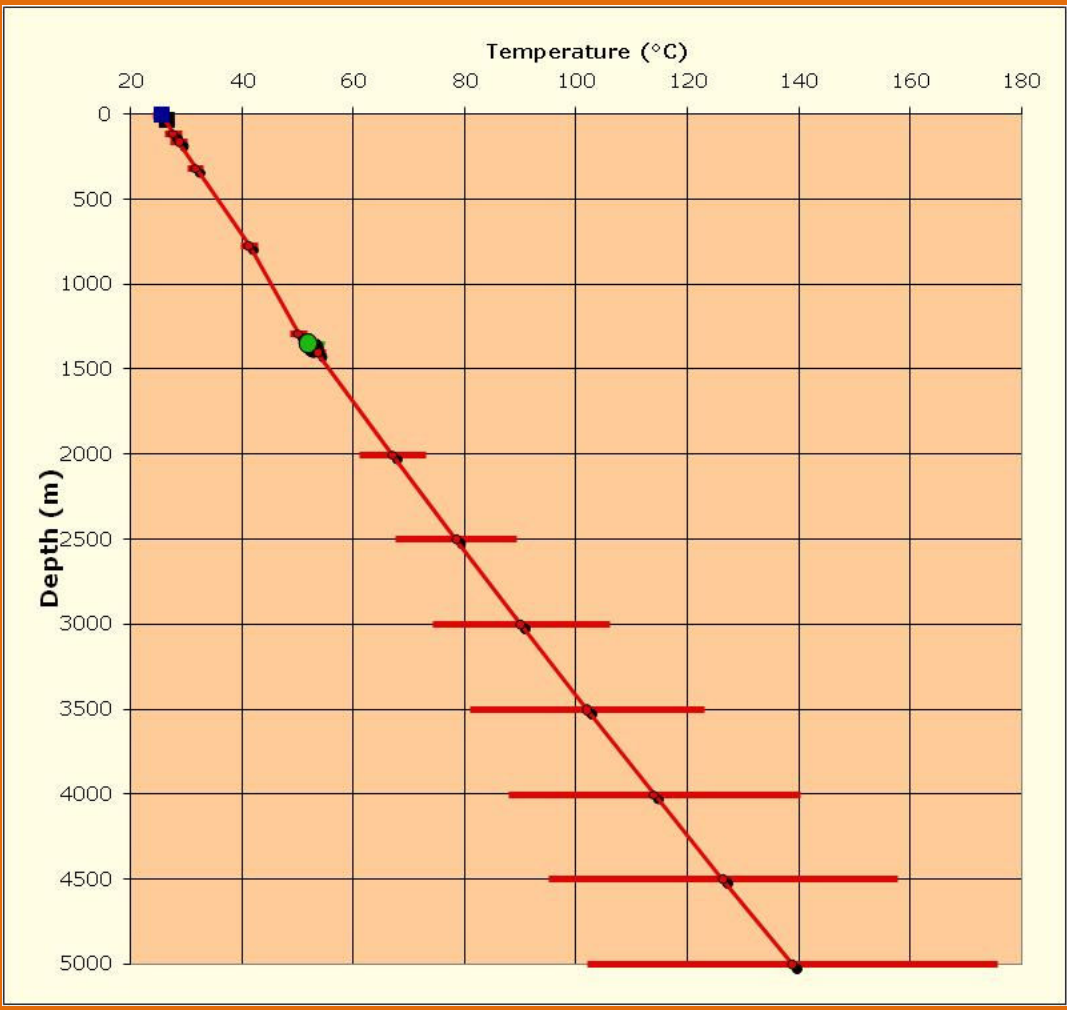
An appendix to the report - Geothermal Energy Potential in Selected Areas of Western Australia (Officer Basin); prepared for the Department of Mines and Petroleum, Western Australia.

Number of layers	16	Up to 50	**Heat flow:** 73 ± 11.8 mW/m2
"Depth" to ground level	0	"KB height"	
Total Depth (m)	7000	From driling datum	
Surface temp. (°C)	25.5	**Boondawari 1**	
Uncertainty in surface T	1.5	±°C	

	Formation Name	Top	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Mundadjini Formation	0	3.80 ± 0.11	0	108
2	Mundadjini Formation [Kari Member]	108	3.80 ± 0.11	0	52
3	Mundadjini Formation	160	3.80 ± 0.11	0	153
4	Spearhole Formation	313	3.54 ± 0.08	0	456
5	Brassey Range Formation	769	4.45 ± 0.30	0	516
6	Table Hill Volcanics [dolerite]	1285	2.25 ± 0.07	0	82
7	Table Hill Volcanics [dolerite]	1367	2.25 ± 0.07	0	3
8	Brassey Range Formation	1370	4.45 ± 0.30	0	30
9	Basement [metasediment]	1400	3.50 ± 1.50	0.66	600
10	Basement [metasediment]	2000	3.50 ± 1.50	0.66	500
11	Basement [metasediment]	2500	3.50 ± 1.50	0.66	500
12	Basement [metasediment]	3000	3.50 ± 1.50	0.66	500
13	Basement [metasediment]	3500	3.50 ± 1.50	0.66	500
14	Basement [metasediment]	4000	3.50 ± 1.50	0.66	500
15	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
16	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1345.6	52	0	2.6912	BHT [time since circ 24 hours]
1345.6	52	0	2.6912	BHT [time since circ 35 hours]



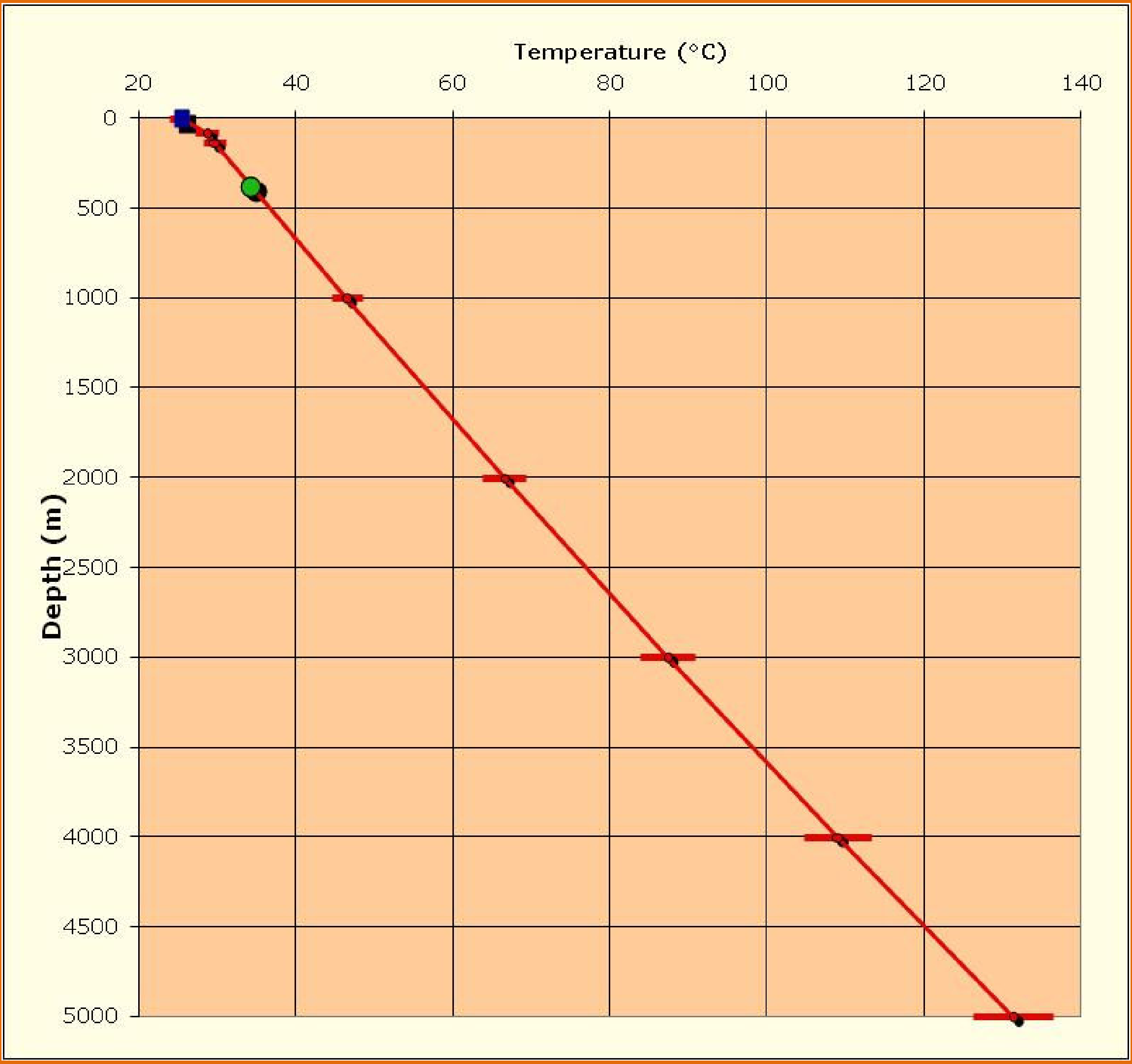
Boondawari 1

Number of layers	11	Up to 50	Heat flow:	50 ± 1.5 mW/m2
"Depth" to ground level	1.52	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	Browne 1		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top	Cond @ 30°C (W/mK)	A ($\mu W/m^3$)	Thickness (m)
1	Samuel Formation	1.52	1.28 ± 0.04	0	82.48
2	Paterson Formation	84	2.58 ± 0.08	0	49
3	Browne Formation	133	2.64 ± 0.10	0	254
4	Browne Formation	387	2.64 ± 0.10	0	613
5	Browne Formation	1000	2.64 ± 0.10	0	1000
6	Browne Formation	2000	2.64 ± 0.10	0	1000
7	Browne Formation	3000	2.64 ± 0.10	0	1000
8	Browne Formation	4000	2.64 ± 0.10	0	1000
9	Browne Formation	5000	2.64 ± 0.10	0	1000
10	Townsend Quartzite	6000	4.45 ± 0.30	0	500
11	Basement [metasediment]	6500	3.50 ± 1.50	0.66	500

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
380.09	34.44	0	0.7602	BHT [time since circ unknown]
379.48	34.44	0	0.759	BHT [time since circ unknown]



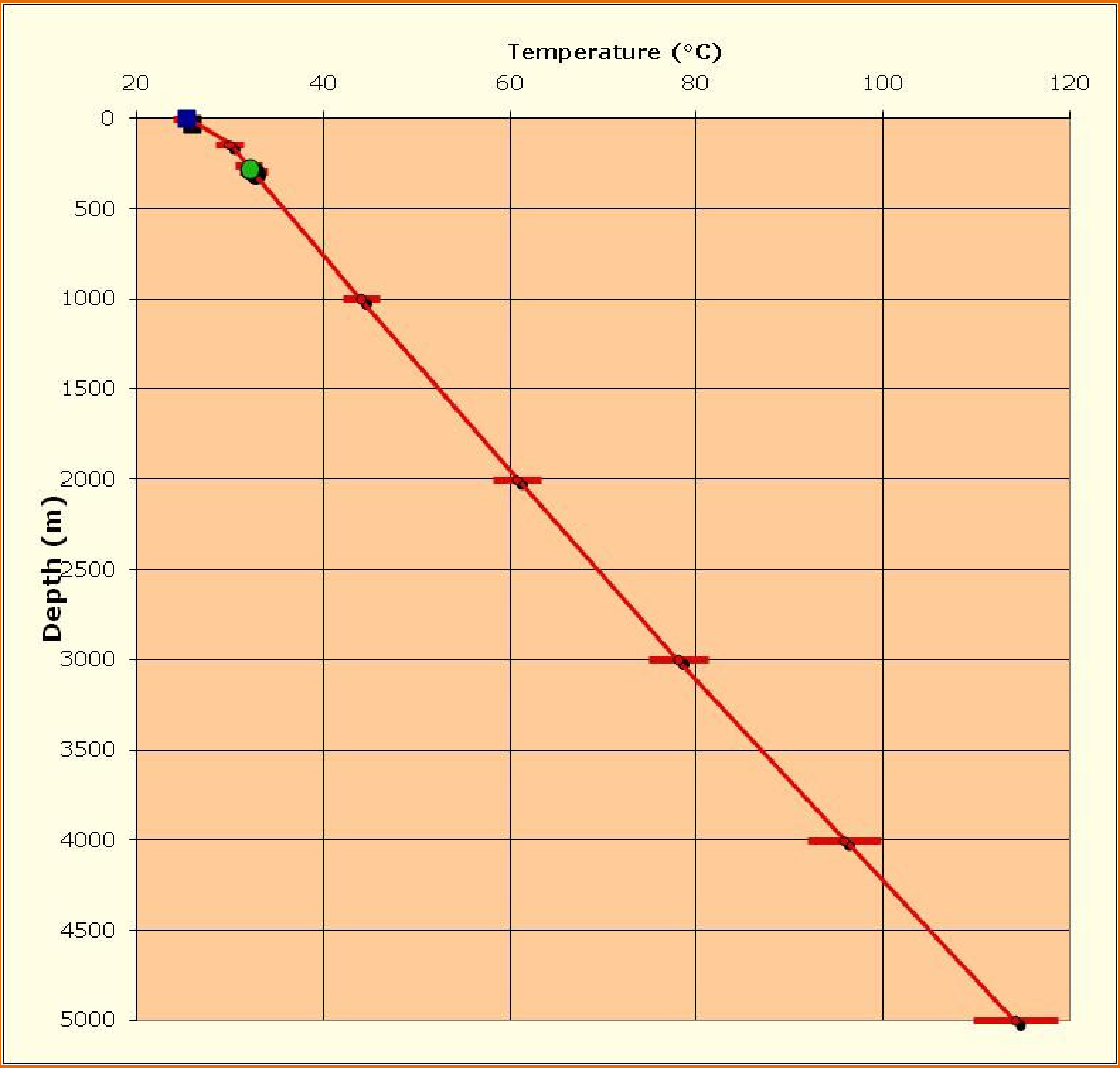
Browne 1

Number of layers	11	Up to 50	Heat flow:	42 ± 1.3 mW/m2
"Depth" to ground level	1.6	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	Browne 2		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Samuel Formation	1.6	1.28 ± 0.04	0	138.4
2	Paterson Formation	140	2.58 ± 0.08	0	122
3	Browne Formation	262	2.64 ± 0.10	0	30.6
4	Browne Formation	292.6	2.64 ± 0.10	0	707.4
5	Browne Formation	1000	2.64 ± 0.10	0	1000
6	Browne Formation	2000	2.64 ± 0.10	0	1000
7	Browne Formation	3000	2.64 ± 0.10	0	1000
8	Browne Formation	4000	2.64 ± 0.10	0	1000
9	Browne Formation	5000	2.64 ± 0.10	0	1000
10	Townsend Quartzite	6000	4.45 ± 0.30	0	500
11	Basement [metasediment]	6500	3.50 ± 1.50	0.66	500

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
281.94	32.22	0	0.5639	BHT [time since circ unknown]
280.11	32.22	0	0.5602	BHT [time since circ unknown]



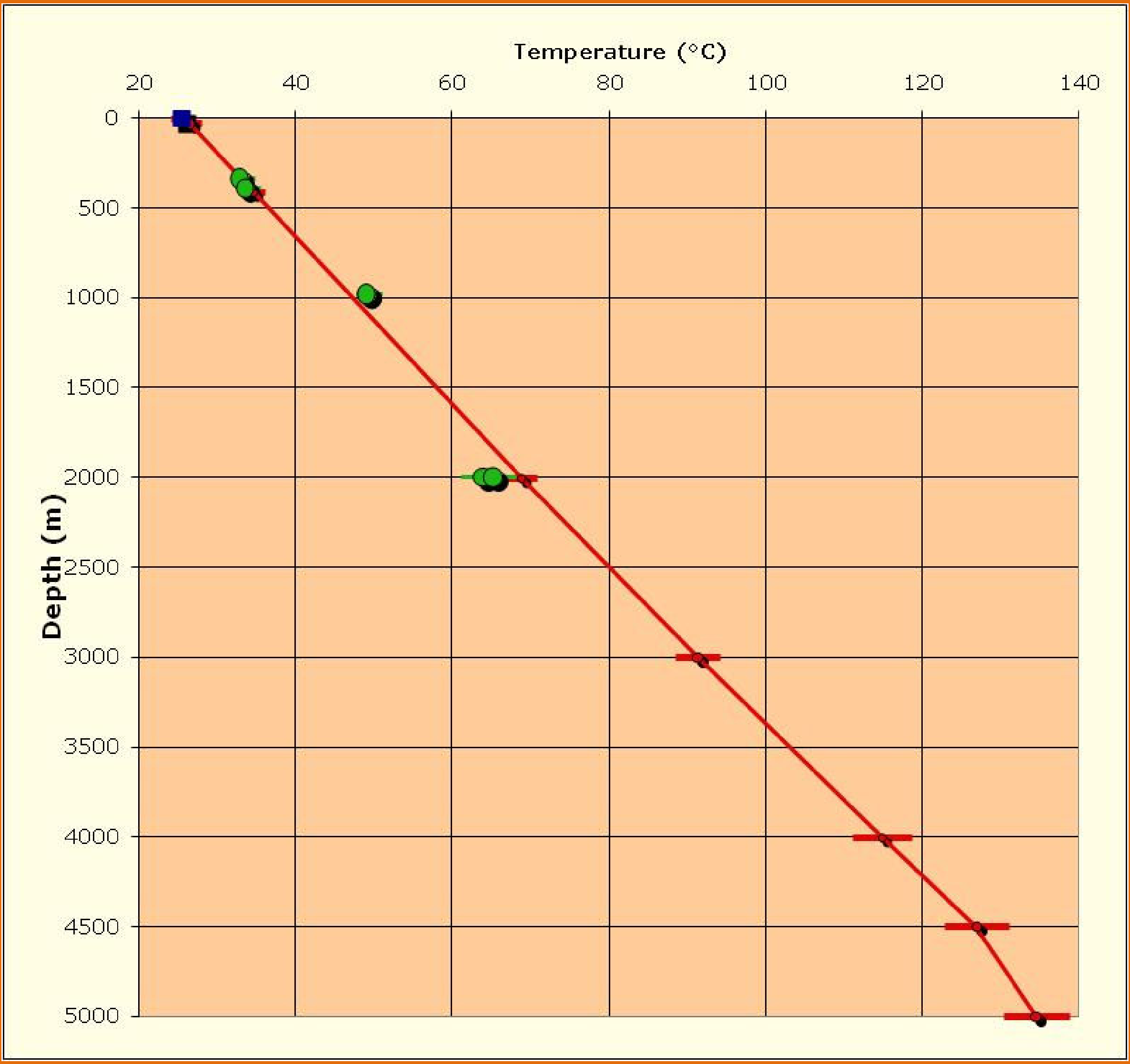
Browne 2

Number of layers	8	Up to 50	**Heat flow:**	54 ± 6.2 mW/m2
"Depth" to ground level	4	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**Dragoon 1**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Samuel Formation	4	1.28 ± 0.04	0	22
2	Paterson Formation	26	2.58 ± 0.08	0	381
3	Browne Formation	407	2.64 ± 0.10	0	1593
4	Browne Formation	2000	2.64 ± 0.10	0	1000
5	Browne Formation	3000	2.64 ± 0.10	0	1000
6	Browne Formation	4000	2.64 ± 0.10	0	500
7	Townsend Quartzite	4500	4.45 ± 0.30	0	500
8	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
333.5	32.8	0	2	Water analysis
384.5	33.5	0	2	Water analysis
972.4	49	0	1.9448	BHT [time since circ 7.5 hours]
976.3	49	0	1.9526	BHT [time since circ 6 hours]
1992.3	64	0	3.9846	BHT [time since circ 10.5 hours]
1995.3	65.1	4	4	Horner [3 values]



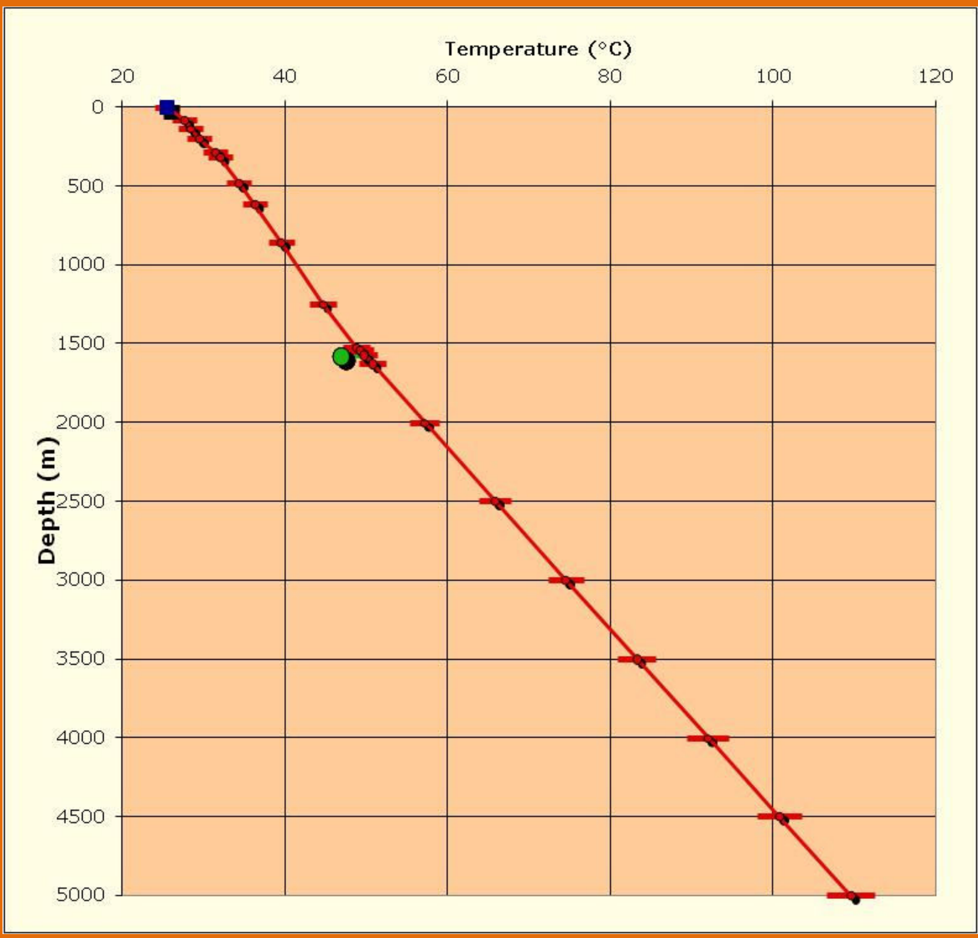
Dragoon 1

Number of layers	21	Up to 50	**Heat flow:**	38 ± 0.4 mW/m2
"Depth" to ground level	0	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**GSWA Empress 1/1A**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A ($\mu W/m^3$)	Thickness (m)
1	Cainozoic [undif.]	0	1.42 ± 0.14	0	79
2	Paterson Formation	79	2.58 ± 0.08	0	52.9
3	Lennis Sandstone	131.9	2.56 ± 0.14	0	69.4
4	Table Hill Volcanics [basalt]	201.3	1.57 ± 0.02	0	84.7
5	unamed Sandstone	286	2.44 ± 0.05	0	31.1
6	Wahlgu Formation	317.1	2.69 ± 0.11	0	165.9
7	Steptoe Formation	483	2.76 ± 0.19	0	134
8	Kanpa Formation	617	2.89 ± 0.40	0	243.8
9	Hussar Formation	860.8	2.99 ± 0.28	0	386.3
10	Browne Formation	1247.1	2.64 ± 0.10	0	274.7
11	Lefroy Formation	1521.8	1.61 ± 0.04	0	18.4
12	Basement [metasediment]	1540.2	2.05 ± 0.05	0.66	29.8
13	Basement [basalt]	1570	2.30 ± 0.05	0.73	54.6
14	Basement [basalt]	1624.6	2.30 ± 0.05	0.73	375.4
15	Basement [basalt]	2000	2.30 ± 0.05	0.73	500
16	Basement [basalt]	2500	2.30 ± 0.05	0.73	500
17	Basement [basalt]	3000	2.30 ± 0.05	0.73	500
18	Basement [basalt]	3500	2.30 ± 0.05	0.73	500
19	Basement [basalt]	4000	2.30 ± 0.05	0.73	500
20	Basement [basalt]	4500	2.30 ± 0.05	0.73	500
21	Basement [basalt]	5000	2.30 ± 0.05	0.73	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1580	47	0	3.16	BHT [time since circ 18.5 hours]
1580	47	0	3.16	BHT [time since circ 7 hours]
1580	47	0	3.16	BHT [time since circ 4:40 hours]
1580	47	0	3.16	BHT [time since circ 23:15 hours]



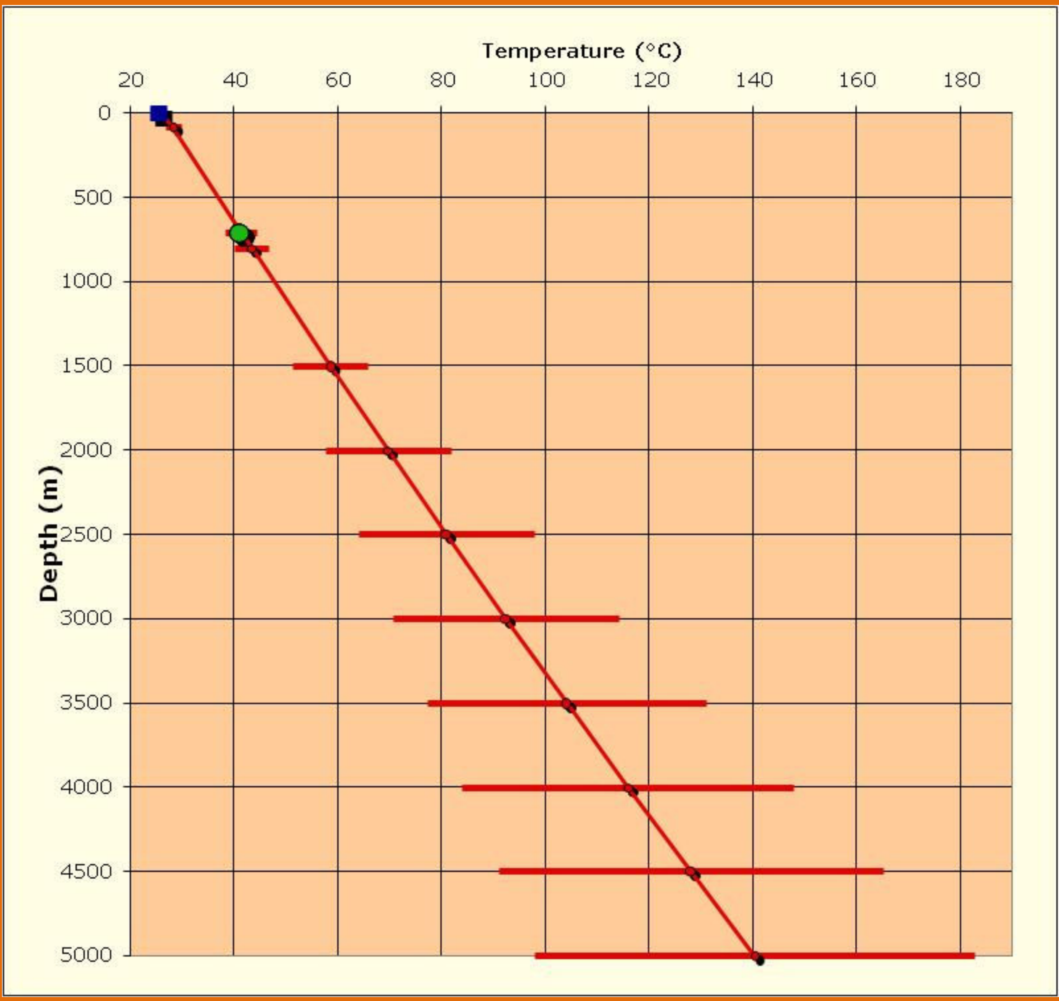
GSWA Empress 1/1A

Number of layers	13	Up to 50	**Heat flow:**	72 ± 11.7 mW/m2
"Depth" to ground level	0	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**GSWA Trainor 1**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m^3)	Thickness (m)
1	Cainozoic [undif.]	0	1.42 ± 0.14	0	9.1
2	McFadden Formation	9.1	2.47 ± 0.36	0	74
3	Cornelia Sandstone	83.1	3.50 ± 0.70	0	625.9
4	Cornelia Sandstone	709	3.50 ± 0.70	0	91
5	Basement [metasediment]	800	3.50 ± 1.50	0.66	700
6	Basement [metasediment]	1500	3.50 ± 1.50	0.66	500
7	Basement [metasediment]	2000	3.50 ± 1.50	0.66	500
8	Basement [metasediment]	2500	3.50 ± 1.50	0.66	500
9	Basement [metasediment]	3000	3.50 ± 1.50	0.66	500
10	Basement [metasediment]	3500	3.50 ± 1.50	0.66	500
11	Basement [metasediment]	4000	3.50 ± 1.50	0.66	500
12	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
13	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
706	41	0	1.412	BHT [time since circ >72:00 hours]
706	41	0	1.412	BHT [time since circ unknown]
709	41	0	1.418	BHT [time since circ >72:00 hours]
709	41	0	1.418	BHT [time since circ >72:00 hours]
709	41	0	1.418	BHT [time since circ unknown]
709	41	0	1.418	BHT [time since circ unknown]



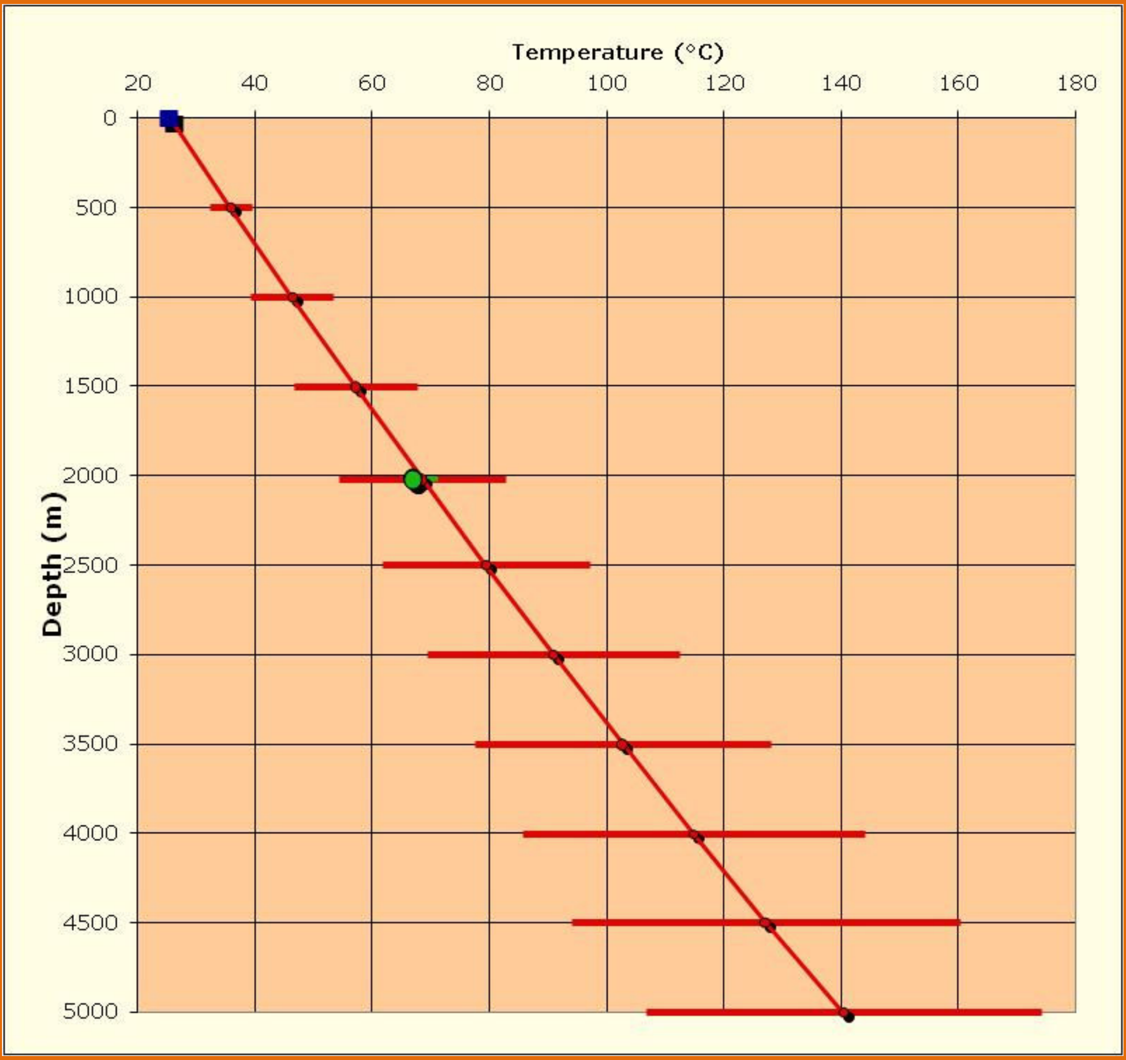
GSWA Trainor 1

Number of layers	12	Up to 50	Heat flow:	75 ± 11.9 mW/m2
"Depth" to ground level	0	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	GSWA Vines 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	Cainozoic [undif.]	0	1.42 ± 0.14	0	4
2	Vines Formation	4	3.70 ± 1.20	0	496
3	Vines Formation	500	3.70 ± 1.20	0	500
4	Vines Formation	1000	3.70 ± 1.20	0	500
5	Vines Formation	1500	3.70 ± 1.20	0	517.5
6	Vines Formation	2017.5	3.70 ± 1.20	0	482.5
7	Vines Formation	2500	3.70 ± 1.20	0	500
8	Vines Formation	3000	3.70 ± 1.20	0	500
9	Vines Formation	3500	3.70 ± 1.20	0	500
10	Vines Formation	4000	3.70 ± 1.20	0	500
11	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
12	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
2011	67	0	4.022	BHT [time since circ unknown]
2018	67	0	4.036	BHT [time since circ 20:10 hours]
2018.3	67	0	4.0366	BHT [time since circ 28:50 hours]



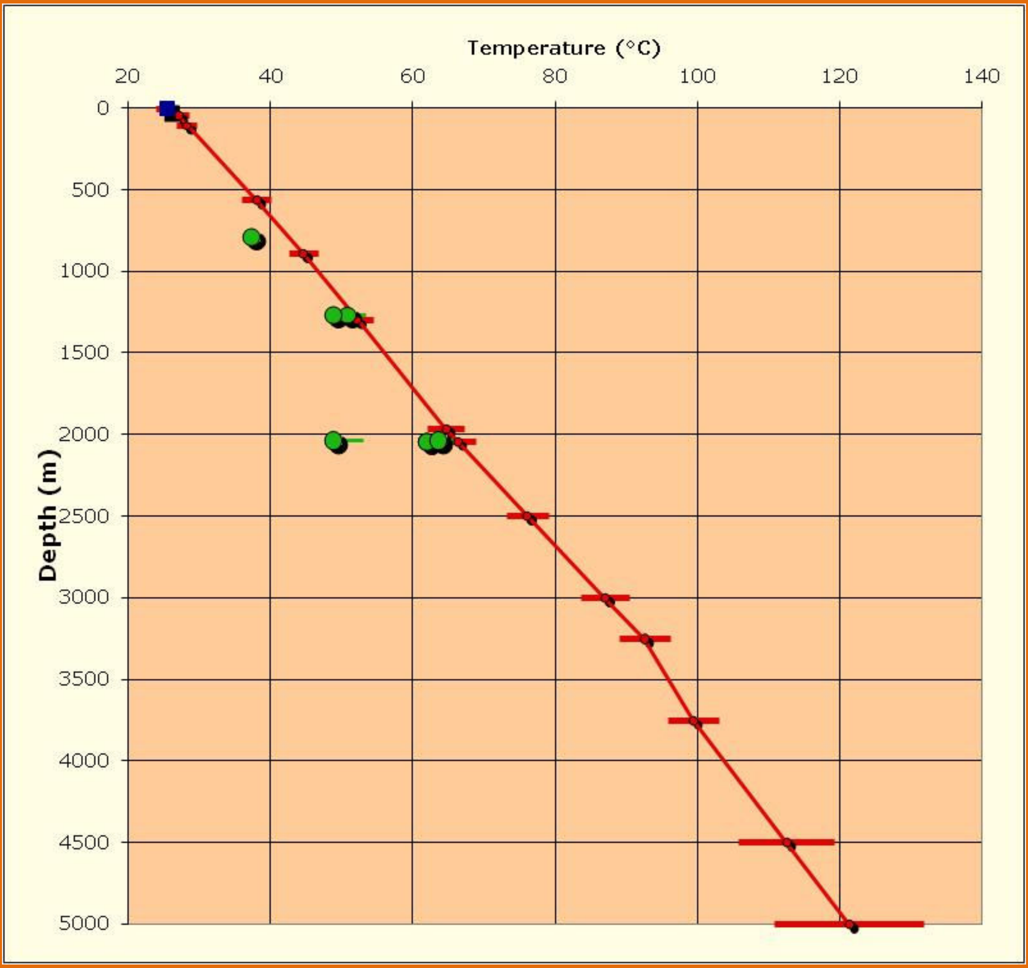
GSWA Vines 1

Number of layers	14	Up to 50	**Heat flow:**	52 ± 6.8 mW/m2	
"Depth" to ground level	4	"KB height"			
Total Depth (m)	7000	From driling datum			
Surface temp. (°C)	25.5	**Hussar 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	Samuel Formation	4	1.28 ± 0.04	0	39
2	Paterson Formation	43	2.58 ± 0.08	0	58
3	McFadden Formation equivalent	101	2.47 ± 0.36	0	459
4	Wahlgu Formation	560	2.69 ± 0.11	0	332
5	Kanpa Formation	892	2.89 ± 0.40	0	402
6	Hussar Formation	1294	2.99 ± 0.28	0	671
7	Browne Formation	1965	2.64 ± 0.10	0	75
8	Browne Formation	2040	2.64 ± 0.10	0	460
9	Browne Formation	2500	2.64 ± 0.10	0	500
10	Browne Formation	3000	2.64 ± 0.10	0	250
11	Townsend Quartzite	3250	4.45 ± 0.30	0	500
12	Basement [metasediment]	3750	3.50 ± 1.50	0.66	750
13	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
14	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1262.5	51	0	2.525	BHT [time since circ 4:30 hours]
785	37.5	0	1.57	BHT [time since circ unknown]
1266	49	0	2.532	BHT [time since circ unknown]
2040	62	0	4.08	BHT [time since circ unknown]
2040	62	0	4.08	BHT [time since circ unknown]
2035	49	0	4.07	BHT [time since circ unknown]
2036.65	63.75	3	3	Horner Plot [4 values]



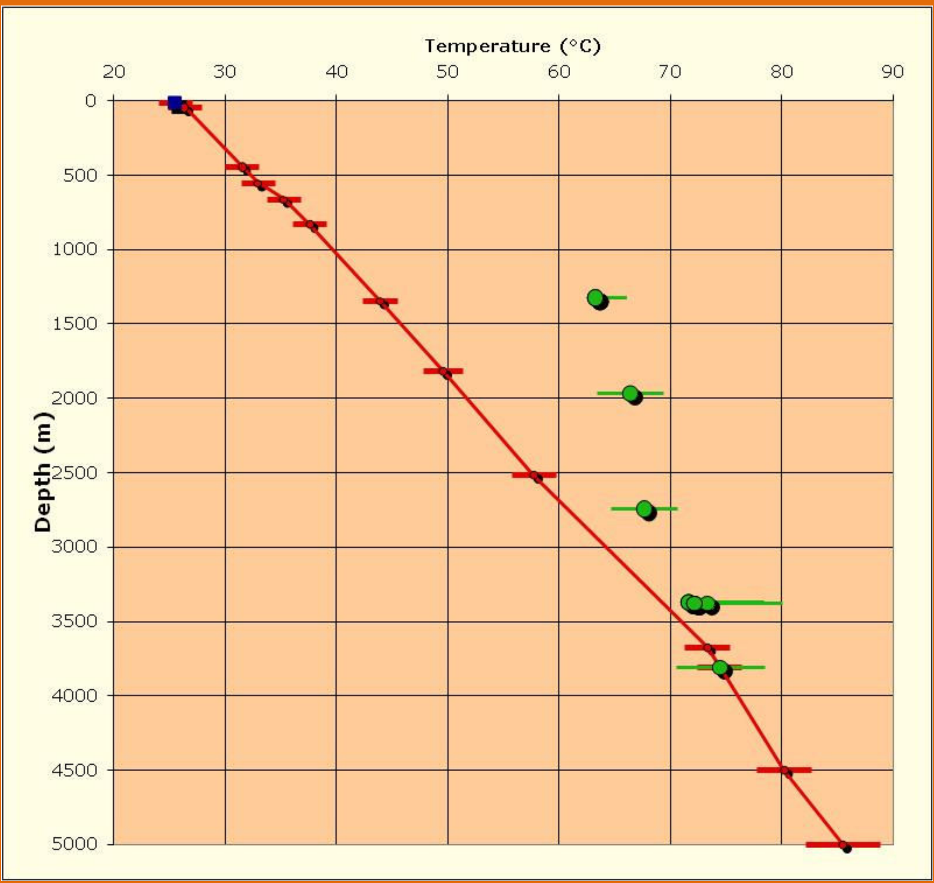
Hussar 1

Number of layers	13	Up to 50	Heat flow:	33 ± 3.9 mW/m2
"Depth" to ground level	6.4	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	Kanpa 1A		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Samuel Formation	6.4	1.28 ± 0.04	0	33.6
2	Paterson Formation	40	2.58 ± 0.08	0	400
3	Lennis Sandstone	440	2.56 ± 0.14	0	107.5
4	Table Hill Volcanics [basalt]	547.5	1.57 ± 0.02	0	109.5
5	McFadden Formation equivalent	657	2.47 ± 0.36	0	172
6	Steptoe Formation	829	2.76 ± 0.19	0	512
7	Kanpa Formation	1341	2.89 ± 0.40	0	476
8	Hussar Formation	1817	2.99 ± 0.28	0	698
9	Browne Formation	2515	2.64 ± 0.10	0	1156
10	Townsend Quartzite	3671	4.45 ± 0.30	0	132
11	Townsend Quartzite	3803	4.45 ± 0.30	0	697
12	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
13	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
1317	63.33	0	2.634	BHT [time since circ 9 hours]
1317	63.33	0	2.634	BHT [time since circ 13 hours]
1323	63.33	0	2.646	BHT [time since circ 5 hours]
1323	63.33	0	2.646	BHT [time since circ 5.25 hours]
1961.4	66.37	3	3	Horner [4 values]
2742.3	67.64	3	3	Horner [4 values]
3366	71.67	0	6.732	BHT [time since circ unknown]
3366	71.67	0	6.732	BHT [time since circ 3.25 hours]
3371	72.22	0	6.742	BHT [time since circ 7.25 hours]
3371	73.33	0	6.742	BHT [time since circ 11.5 hours]
3371	72.22	0	6.742	BHT [time since circ 11.5 hours]
3371	72.22	0	6.742	BHT [time since circ 15.75 hours]
3803	74.46	4	4	Horner [3 values]



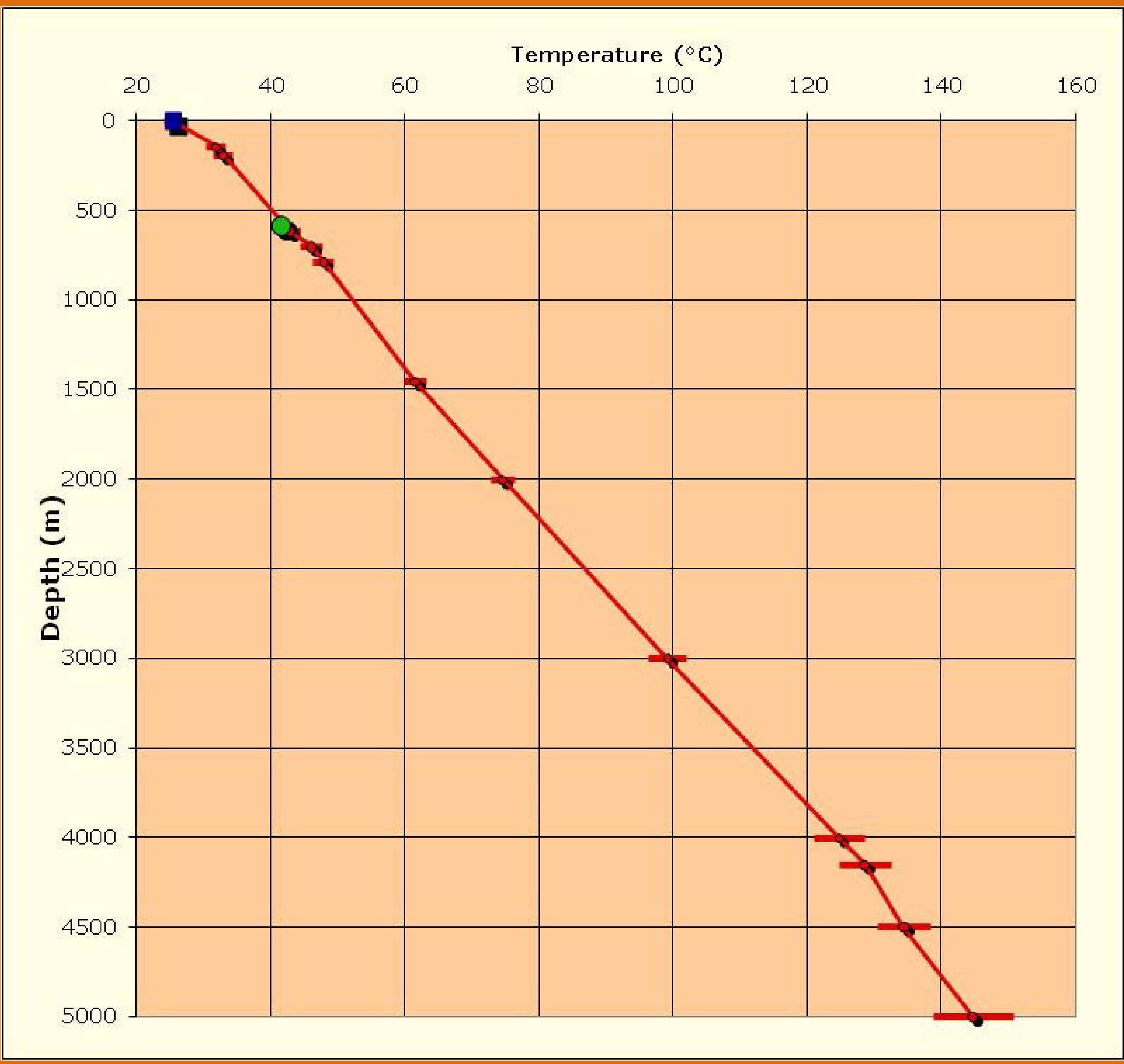
Kanpa 1A

Number of layers	14	Up to 50	**Heat flow:**	58 ± 6.9 mW/m2
"Depth" to ground level	2	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**Lennis 1**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A	Thickness (m)
1	Samuel Formation	2	1.28 ± 0.04	0	138
2	Paterson Formation	140	2.58 ± 0.07	0	47
3	Lennis Sandstone	187	2.56 ± 0.14	0	425
4	Table Hill Volcanics [basalt]	612	1.57 ± 0.02	0	3
5	Table Hill Volcanics [basalt]	615	1.57 ± 0.02	0	85
6	Kanpa Formation	700	2.89 ± 0.28	0	85
7	Hussar Formation	785	2.99 ± 0.13	0	665
8	Browne Formation	1450	2.64 ± 0.10	0	550
9	Browne Formation	2000	2.64 ± 0.10	0	1000
10	Browne Formation	3000	2.64 ± 0.10	0	1000
11	Browne Formation	4000	2.64 ± 0.10	0	150
12	Townsend Quartzite	4150	4.45 ± 0.30	0	350
13	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
14	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
582.78	41.67	0	1.1656	BHT [time since circ unknown]
583.08	41.67	0	1.1662	BHT [time since circ unknown]



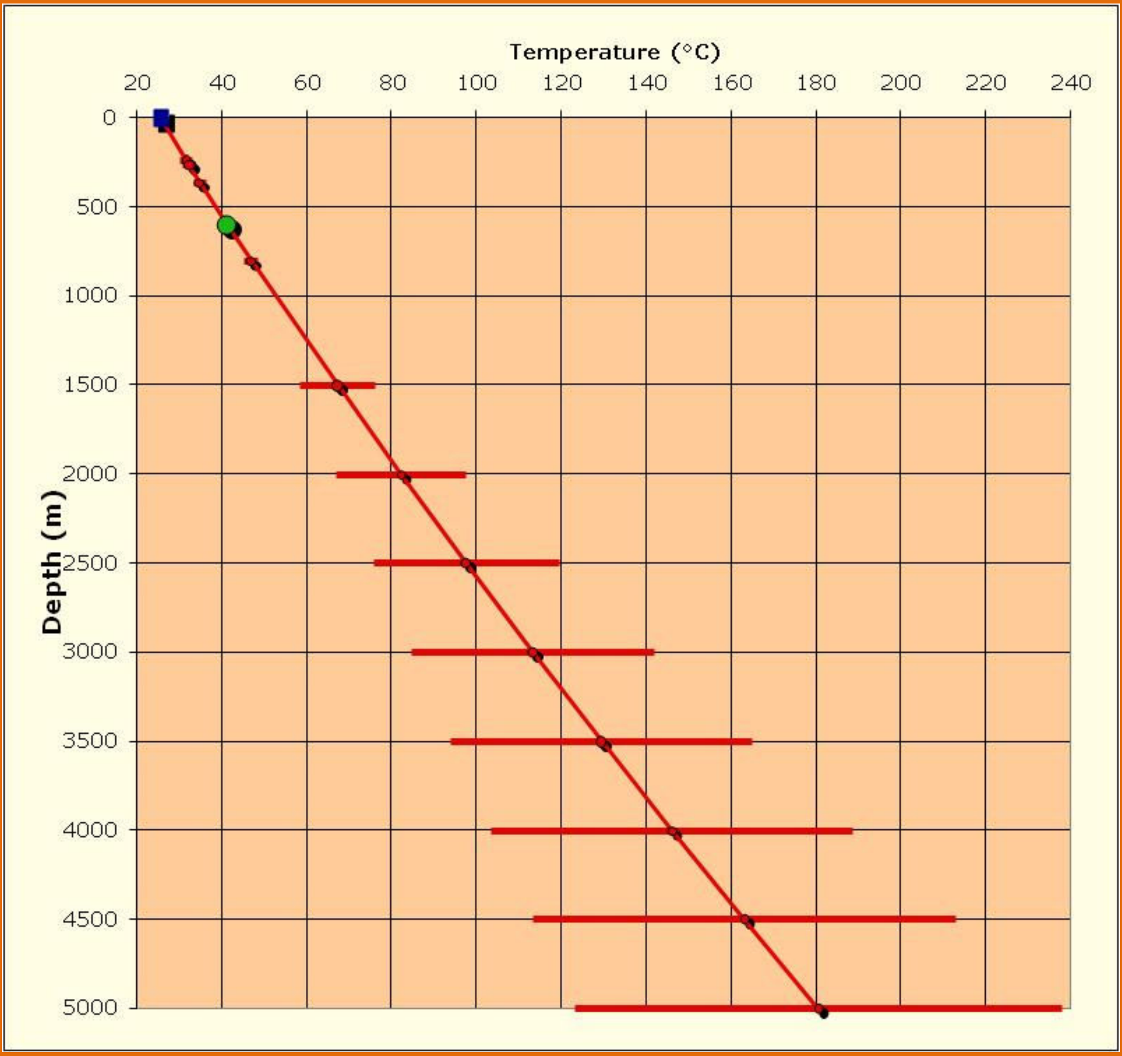
Lennis 1

Number of layers	14	Up to 50	**Heat flow:** 95 ± 15.8 mW/m2
"Depth" to ground level	0.8	"KB height"	
Total Depth (m)	7000	From driling datum	
Surface temp. (°C)	25.5	**Mundadjini 1**	
Uncertainty in surface T	1.5	±°C	

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Mundadjini Formation	0.8	3.80 ± 0.11	0	235.7
2	Mundadjini Formation [Kari Member]	236.5	3.80 ± 0.11	0	28
3	Mundadjini Formation	264.5	3.80 ± 0.11	0	94.5
4	Spearhole Formation	359	3.54 ± 0.08	0	241
5	Spearhole Formation	600	3.54 ± 0.08	0	200
6	Basement [metasediment]	800	3.50 ± 1.50	0.66	700
7	Basement [metasediment]	1500	3.50 ± 1.50	0.66	500
8	Basement [metasediment]	2000	3.50 ± 1.50	0.66	500
9	Basement [metasediment]	2500	3.50 ± 1.50	0.66	500
10	Basement [metasediment]	3000	3.50 ± 1.50	0.66	500
11	Basement [metasediment]	3500	3.50 ± 1.50	0.66	500
12	Basement [metasediment]	4000	3.50 ± 1.50	0.66	500
13	Basement [metasediment]	4500	3.50 ± 1.50	0.66	500
14	Basement [metasediment]	5000	3.50 ± 1.50	0.66	2000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
598.7	41	0	1.1974	BHT [time since circ 3:30 hours]



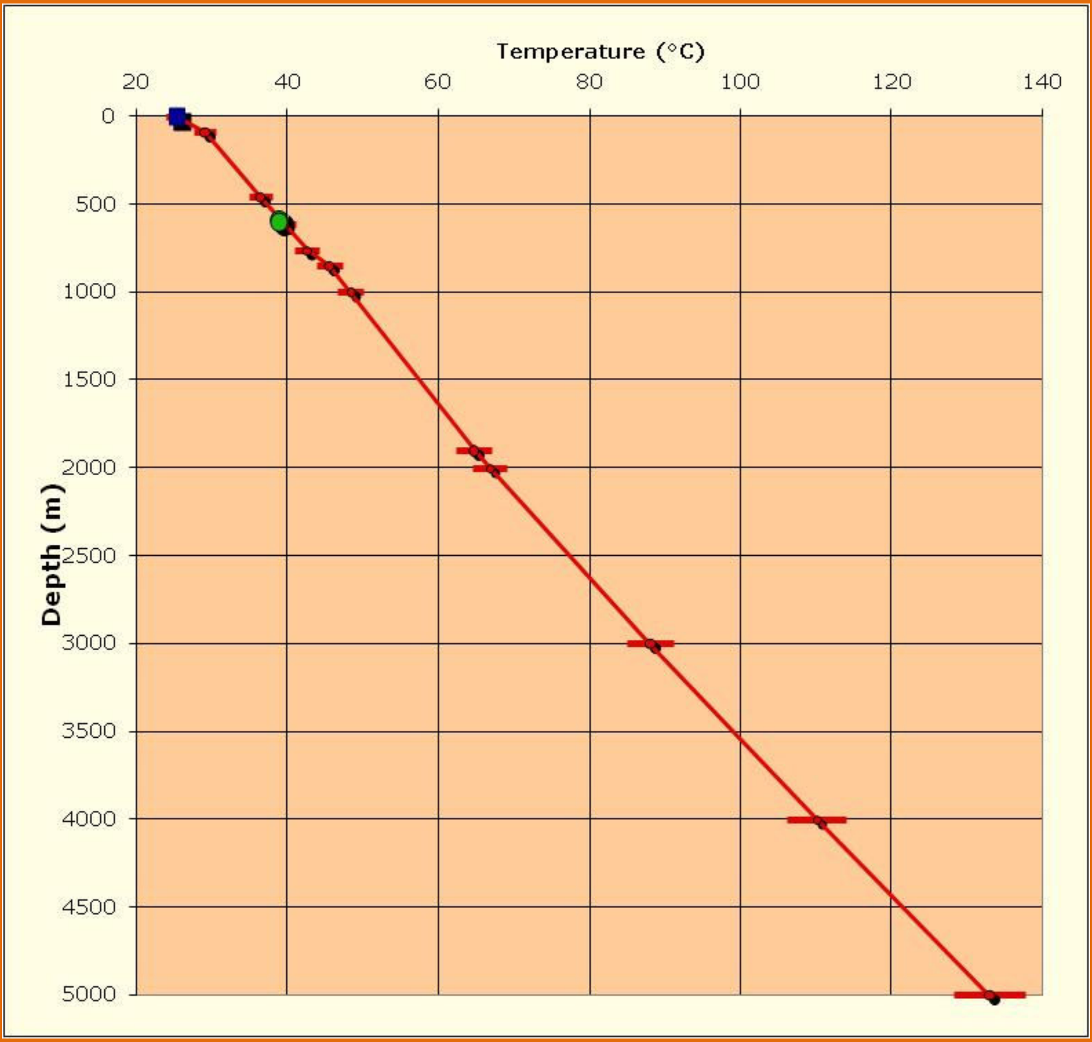
Mundadjini 1

Number of layers	15	Up to 50	**Heat flow:** 51 ± 3.0 mW/m2
"Depth" to ground level	1	"KB height"	
Total Depth (m)	7000	From driling datum	
Surface temp. (°C)	25.5	**Yowalga 1**	
Uncertainty in surface T	1.5	±°C	

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Mesozoic [undif.]	1	1.42 ± 0.14	0	1
2	Samuel Formation	2	1.28 ± 0.04	0	90
3	Paterson Formation	92	2.58 ± 0.08	0	366
4	Lennis Sandstone	458	2.56 ± 0.14	0	155
5	Lennis Sandstone	613	2.56 ± 0.14	0	147
6	Table Hill Volcanics [basalt]	760	1.57 ± 0.02	0	90
7	Kanpa Formation	850	2.89 ± 0.40	0	150
8	Hussar Formation	1000	2.99 ± 0.28	0	900
9	Browne Formation	1900	2.64 ± 0.10	0	100
10	Browne Formation	2000	2.64 ± 0.10	0	1000
11	Browne Formation	3000	2.64 ± 0.10	0	1000
12	Browne Formation	4000	2.64 ± 0.10	0	1000
13	Browne Formation	5000	2.64 ± 0.10	0	500
14	Townsend Quartzite	5500	4.45 ± 0.30	0	500
15	Basement [metasediment]	6000	3.50 ± 1.50	0.66	1000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
579.42	38.89	0	1.1588	BHT [time since circ unknown]
598.02	38.89	0	1.196	BHT [time since circ unknown]



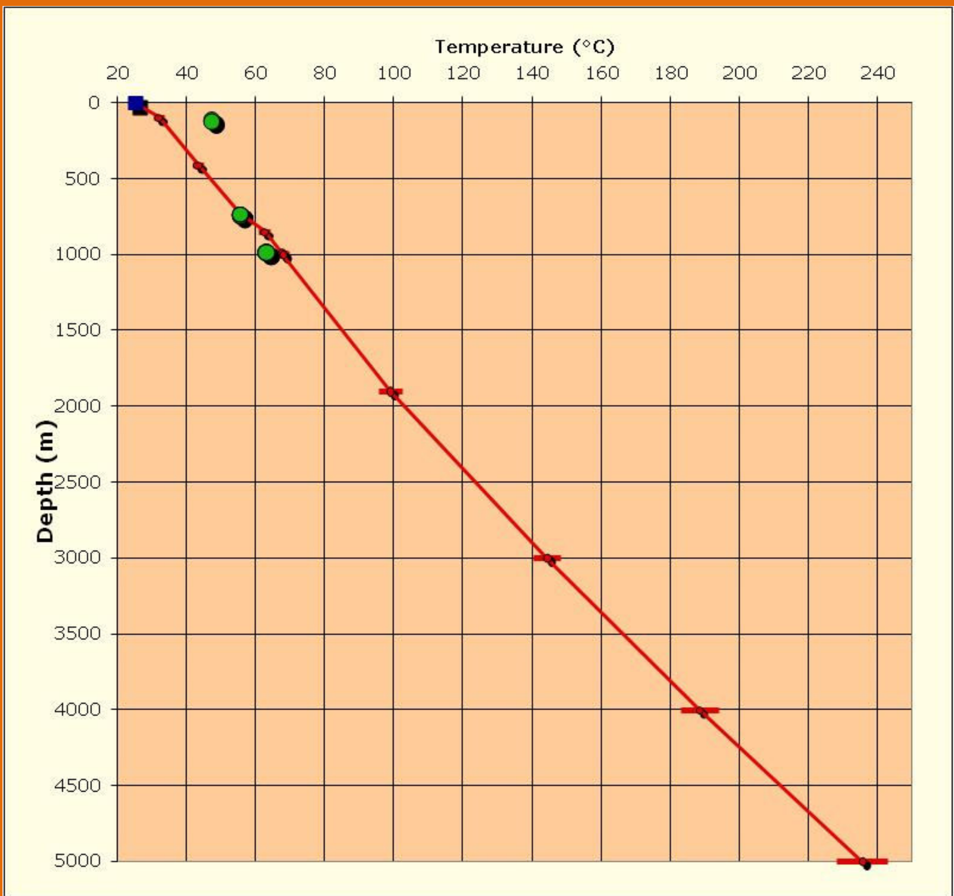
Yowalga 1

Number of layers	13	Up to 50	**Heat flow:**	92 ± 5.8 mW/m2
"Depth" to ground level	4.1	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**Yowalga 2**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m³)	Thickness (m)
1	Samuel Formation	4.1	1.28 ± 0.04	0	89.9
2	Paterson Formation	94	2.58 ± 0.08	0	312.9
3	Lennis Sandstone	406.9	2.56 ± 0.14	0	321.1
4	Table Hill Volcanics [basalt]	728	1.57 ± 0.02	0	118
5	Kanpa Formation	846	2.89 ± 0.40	0	143.4
6	Kanpa Formation	989.4	2.89 ± 0.40	0	10.6
7	Hussar Formation	1000	2.99 ± 0.28	0	900
8	Browne Formation	1900	2.64 ± 0.10	0	1100
9	Browne Formation	3000	2.64 ± 0.10	0	1000
10	Browne Formation	4000	2.64 ± 0.10	0	1000
11	Browne Formation	5000	2.64 ± 0.10	0	500
12	Townsend Quartzite	5500	4.45 ± 0.30	0	500
13	Basement [metasediment]	6000	3.50 ± 1.50	0.66	1000

Downhole temperature data (°C): **Maximum 20 values**

Depth (m)	Value	-uncert	+uncert	Comment:
114.3	47.22	0	0.2286	BHT [time since circ unknown]
737	55.56	0	1.474	BHT [time since circ unknown]
982.06	63.33	0	1.9641	BHT [time since circ unknown]
118.26	47.22	0	0.2365	BHT [time since circ unknown]
740.66	55.56	0	1.4813	BHT [time since circ unknown]
984.8	63.33	0	1.9696	BHT [time since circ unknown]
738.22	55.56	0	1.4764	BHT [time since circ unknown]
981.45	63.33	0	1.9629	BHT [time since circ unknown]
728.47	55.56	0	1.4569	BHT [time since circ unknown]
982.98	63.33	0	1.966	BHT [time since circ unknown]
728.47	55.56	0	1.4569	BHT [time since circ unknown]
728.47	55.56	0	1.4569	BHT [time since circ unknown]
982.98	63.33	0	1.966	BHT [time since circ unknown]



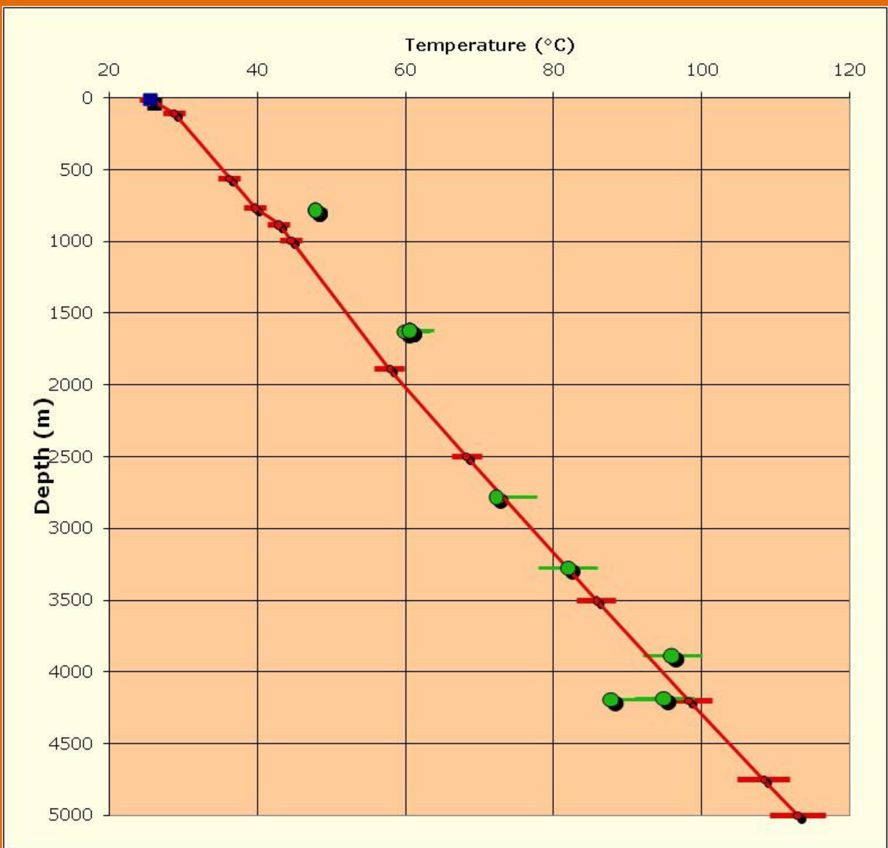
Yowalga 2

Number of layers	14	Up to 50	**Heat flow:**	42 ± 2.4 mW/m2
"Depth" to ground level	7.1	"KB height"		
Total Depth (m)	7000	From driling datum		
Surface temp. (°C)	25.5	**Yowalga 3**		
Uncertainty in surface T	1.5	±°C		

	Formation Name	Top (m)	Cond @ 30°C (W/mK)	A (μW/m^3)	Thickness (m)
1	Samuel Formation	7.1	1.28 ± 0.04	0	98.9
2	Paterson Formation	106	2.58 ± 0.08	0	449
3	Lennis Sandstone	555	2.56 ± 0.14	0	208
4	Table Hll Volcanics [basalt]	763	1.57 ± 0.02	0	117
5	Kanpa Formation	880	2.89 ± 0.40	0	111
6	Hussar Formation	991	2.99 ± 0.28	0	897
7	Browne Formation	1888	2.64 ± 0.10	0	612
8	Browne Formation	2500	2.64 ± 0.10	0	1000
9	Browne Formation	3500	2.64 ± 0.10	0	696.5
10	Browne Formation	4196.5	2.64 ± 0.10	0	553.5
11	Browne Formation	4750	2.64 ± 0.10	0	250
12	Browne Formation	5000	2.64 ± 0.10	0	500
13	Townsend Quartzite	5500	4.45 ± 0.30	0	500
14	Basement [metasediment]	6000	3.50 ± 1.50	0.66	1000

Downhole temperature data (°C):

Depth (m)	Value	-uncert	+uncert	Comment:
775	47.78	0	1.55	BHT [time since circ 4 hours]
778.5	47.78	0	1.557	BHT [time since circ 9.5 hours]
777	47.78	0	1.554	BHT [time since circ 6 hours]
1622	60	0	3.244	BHT [time since circ 7 hours]
1618	60.56	0	3.236	BHT [time since circ 8.5 hours]
1617	60.56	0	3.234	BHT [time since circ 6 hours]
1619	60.56	0	3.238	BHT [time since circ 16 hours]
2777	72.2	0	5.554	BHT [time since circ unknown]
4187	87.78	0	8.374	BHT [time since circ unknown]
3269.5	81.94	4	4	Horner [3 values]
3885.8	95.98	4	4	Horner [3 values]
4179	94.93	4	4	Horner [3 values]



Yowalga 3

Hot Dry Rocks Pty Ltd
Geothermal Energy Consultants

HEAD OFFICE
PO Box 251
South Yarra, Vic 3141
Australia
T +61 3 9867 4078
F +61 3 9279 3955
E info@hotdryrocks.com
W www.hotdryrocks.com

ABN: 12 114 617 622

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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 (Officer 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 biotur-bated; 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; high-ly fractured [healed? Doubtful drilling induced?]	3825.70	3825.90			DIR149
Yowalga 2	Officer	Kanpa Formation	reddish finely la-minated interbed-ded 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.

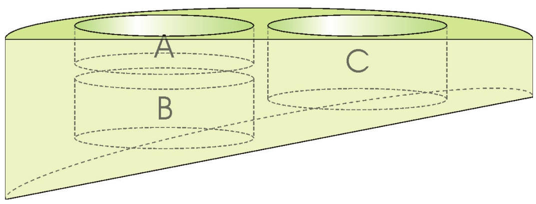
Where possible, three prisms were cut from each core specimen, each approximately ⅓ to ½ the length of the sample in thickness, and each sample was ground flat and polished. These are indicated on Table 2 by the description 'Whole rock'.

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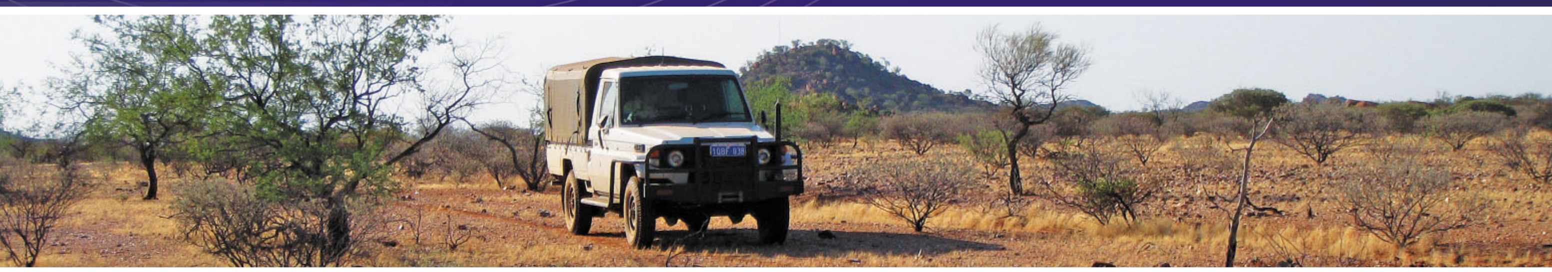

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