SEL26/2005

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# APPENDIX 8

# Reports by Hot Dry Rocks Pty Ltd on heat flow modelling, SEL26/2005

**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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# Heat flow modelling of selected wells in SEL26/2005, Tasmania



Prepared for KUTh Energy Ltd (KEN)

Date 21 APR 2008 Draft 1.1

Gareth Cooper & Ben Waining

## Executive summary

Four (4) shallow wells in SEL26/2005 (Tasmania) were measured by Hot Dry Rocks Pty Ltd (HDRPL) for equilibrated downhole temperature. The same wells were sampled and core samples measured for rock thermal conductivity. These data have been combined using HDRPLs 1D Heat Flow Modelling Software to produce modelled surface heat flow values for each well.

The resulting surface heat flows for each well are summarised in the table below:-

| **Well** | Snow-1 | Lake Leake-1 | Elizabeth-1 | Tooms-1 |
|---|---|---|---|---|
| **Modelled Heat Flow ($mW/m^2$)** | 92.0 ± 2.3 | 92.0 ± 2.9 | 94.0 ± 2.4 | 96.0 ± 2.5*<br>63.3 ± 1.3* |

All four wells have consistent heat flow values (ranging from 92-96 $mW/m^2$) although Tooms-1 has an unusual temperature profile suggesting possible convection at the base of the well. This has the influence of reducing heat flow at the base of Tooms-1 to 63 $mW/m^2$, although the overall modelled surface heat flow of the well is approximately 96 $mW/m^2$.

The range of heat flow values modelled for these four Tasmanian wells is within the range of heat flow values reported for parts of the Cooper Basin and the Adelaide Fold and Thrust Belt (South Australia) and fall within the upper 17% of heat flow values recorded for Australia in the *Global Heat Flow Database*.

# Table of Contents

## 1.0 Introduction

Hot Dry Rocks Pty Ltd (HDRPL) has been commissioned by KUTh Energy Ltd (KEN) to undertake heat flow modelling of selected wells in their tenement (SEL26/2005).

SEL26/2005 is located in eastern Tasmania and extends from George Town in the north of the state to Hobart in the south.  As part of its work program, KEN is undertaking a shallow drilling program to define heat flows within their tenement. This report provided modelled heat flow values for the following shallow wells:-

- Elizabeth-1
- Tooms-1
- Snow-1
- Lake Leake-1

Heat flow models described in this report incorporate rock thermal conductivity measurements and calibrated precision temperature logs recently undertaken by HDRPL for the same wells.



## 2.0 Introduction to heat flow

Heat flow is a power unit expressed at surface ($mW/m^2$) and is a function 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. Temperatures are usually 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 $T_0$ plus the product of heat flow **Q** and thermal resistance **R**, such that:

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

Consequently the most highly 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 a product of temperature gradient and rock thermal conductivity and is therefore a modelled value (not directly measured). Consequently, the modelling of heat flow is a precision skill that requires a detailed understanding of physical conditions in the bore and the physical properties of the rocks; including advective processes that may influence bore temperature (such as ground water flow) and the temperature dependence of conductivity.

HDRPL utilises its own 1D Heat Flow Modelling Software for the modelling of both advective influences and temperature dependence. The results of 1D heat flow modelling should be treated with caution when extrapolating data spatially over considerable distance.

# 3.0 Results of heat flow models

## 3.1 Summary of modelled surface heat flows

A summary of modelled surface heat flow results is shown in table 1. Sections below describe detailed information about each model.

**Table 1.** Summary of modelled surface heat flows for shallow wells in SEL26/2005

| **Well** | Snow-1 | Lake Leake-1 | Elizabeth-1 | Tooms-1 |
|---|---|---|---|---|
| **Modelled Heat Flow ($mW/m^2$)** | 92.0 ± 2.3 | 92.0 ± 2.9 | 94.0 ± 2.4 | 96.0 ± 2.5*<br>63.3 ± 1.3* |

* Tooms-1 heat flow appears to be influenced by heat entering the bore via an extensive fracture and fault network at about 170-180 m. This has perturbed the modelled heat flow which is more likely to be around 96 $mW/m^2$ based on modelled results.

### 3.2 Snow-1 modelled surface heat flow

The heat flow model for Snow-1 (Fig. 1) illustrates a very good fit between measured conductivity and calibrated precision temperature data. Upper conductivities values (not measured) have been assumed at 2.4 W/mK being the upper end of the measured distribution. The modelled surface heat flow is **92.0 ±2.3 mW/m$^2$** over the conductivity-constrained interval.

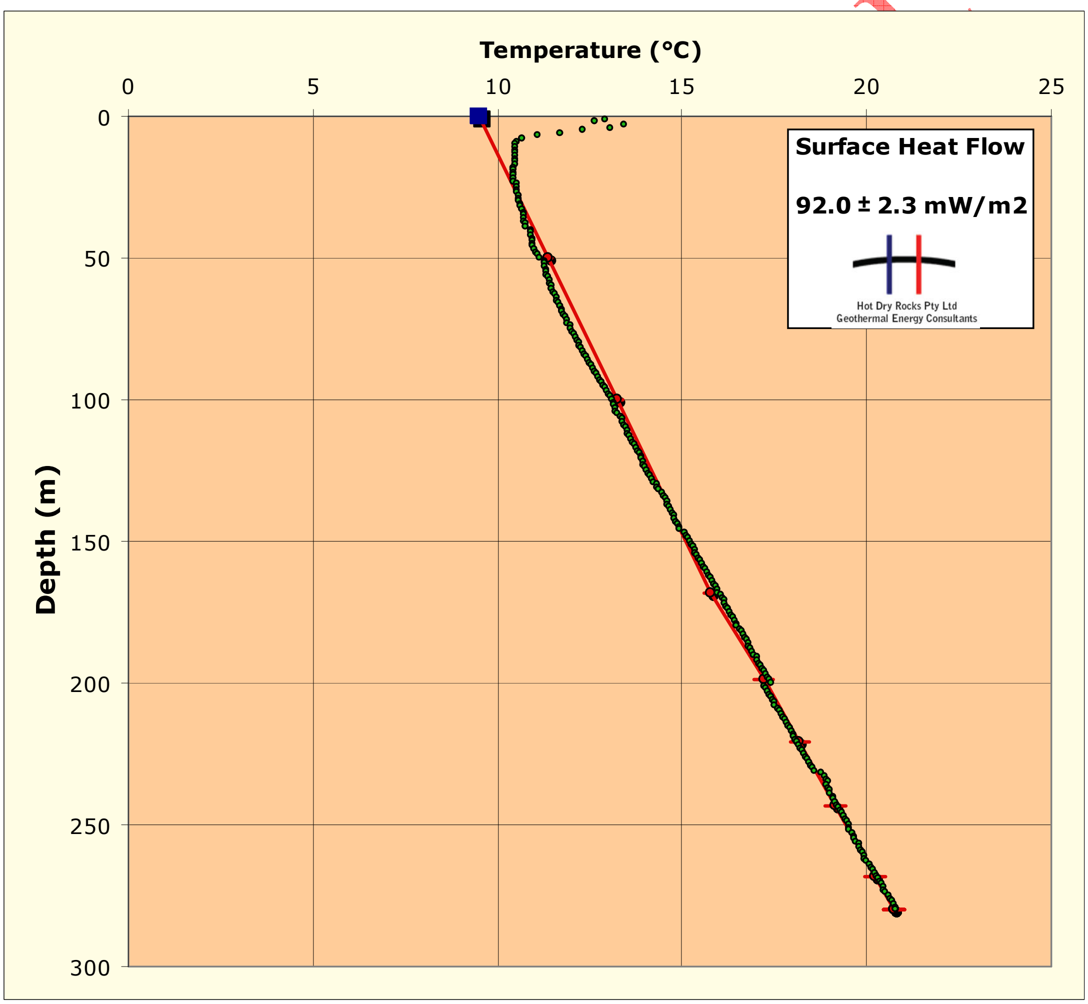


**Figure 1**. Snow-1 – modelled surface heat flow based on rock thermal conductivity data (red points) and precision temperature logs (green line). Upper divergence in temperatures is due to air and cooled water at the top of the bore.

### 3.3 Lake Leake-1 modelled surface heat flow

The heat flow model for Lake Leake-1 (Fig.2) illustrates an excellent fit between measured conductivity and calibrated precision temperature data. Upper conductivities values (not measured) have been assumed at 2.4 W/mK being the upper end of the measured distribution. The modelled surface heat flow is **92.0±2.9 mW/m$^2$** over the conductivity-constrained interval.

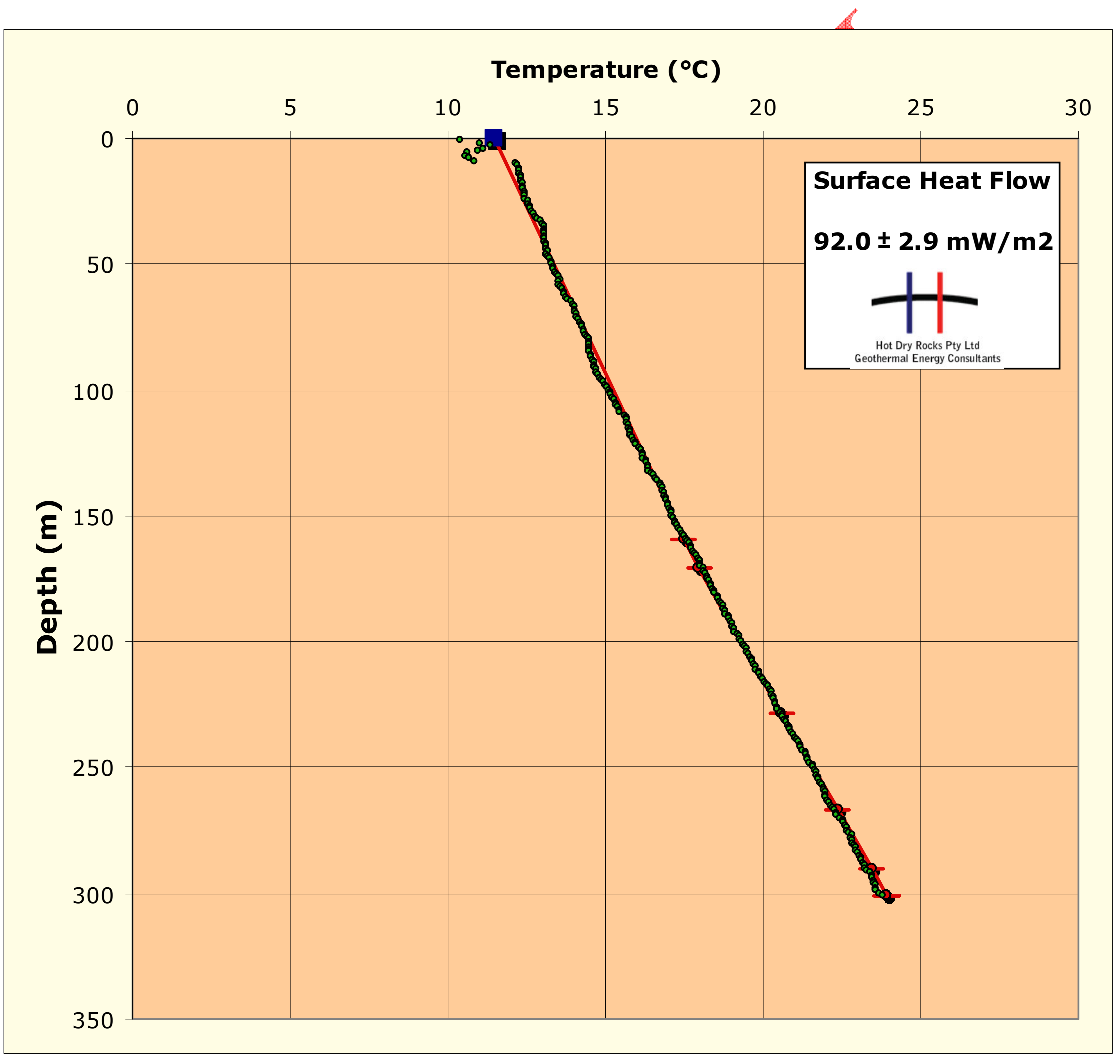


**Figure 2**. Lake Leake-1 – modelled surface heat flow based on rock thermal conductivity data (red points) and precision temperature logs (green line). Upper divergence in temperatures is due to air and cooled water at the top of the bore.

### 3.4 Elizabeth-1 modelled surface heat flow

The heat flow model for Elizabeth-1 (Fig.3) illustrates an excellent fit between measured conductivity and calibrated precision temperature data. Upper conductivities values (not measured) have been assumed at 2.4 W/mK being the upper end of the measured distribution. The modelled surface heat flow is **94±2.4 mW/m²** over the conductivity-constrained interval.

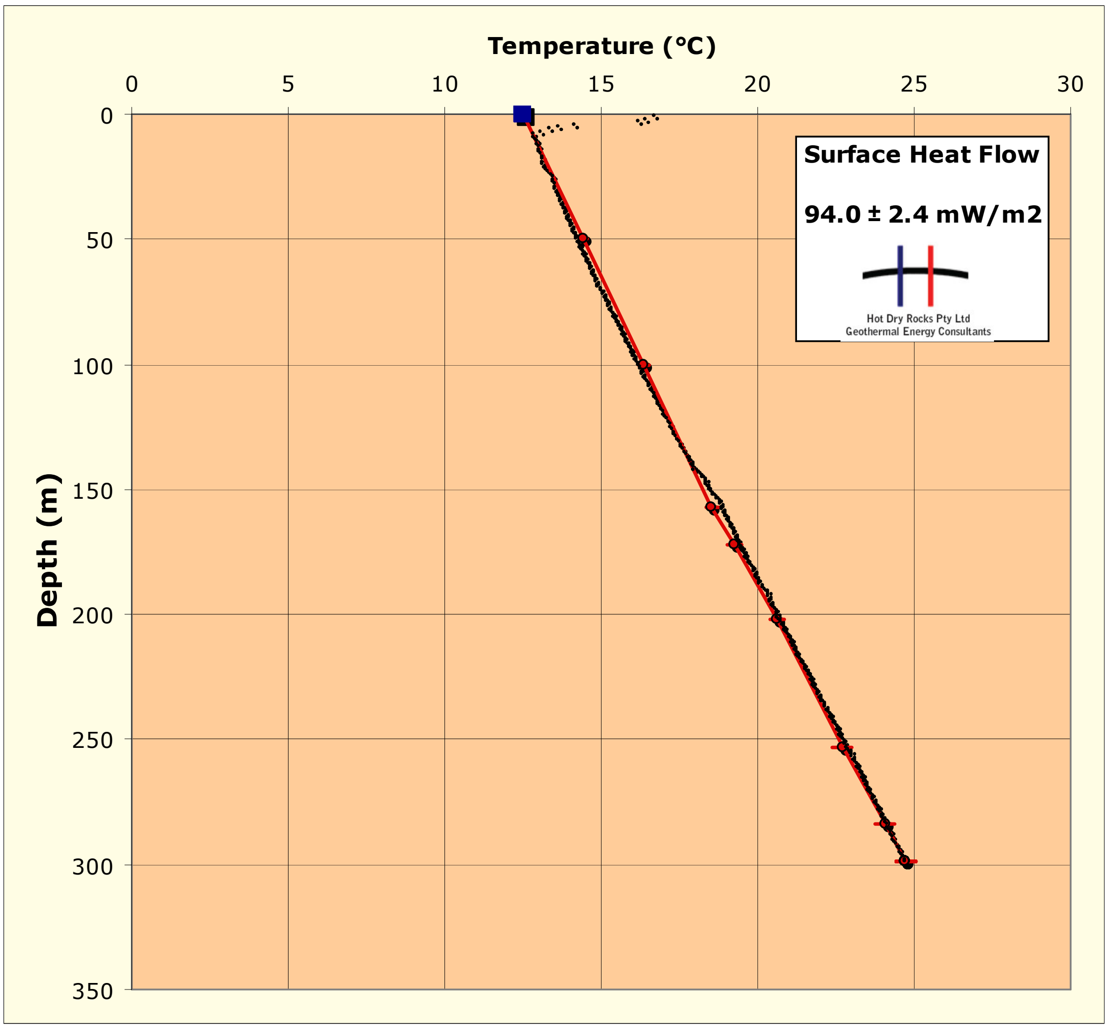


**Figure 3**. Elizabeth-1 – modelled surface heat flow based on rock thermal conductivity data (red points) and precision temperature logs (green line). Upper divergence in temperatures is due to air and cooled water at the top of the bore.

### 3.5 Tooms-1 modelled surface heat flow

The heat flow model for Tooms-1 (Fig.4) illustrates a good fit between measured conductivity and calibrated precision temperature data. Upper conductivities values (not measured) have been assumed at 2.4 W/mK being the upper end of the measured distribution.

Modelling for Tooms-1 is however complicated by the strongly sygmoidal geometry of the temperature profile, indicating probable convection within the deepest part of the bore. Modelling suggests that a significant amount of heating may be added between 154 and 204m depth with the addition of approximately 62 mW/m$^2$. This may suggest shallow warm waters are entering the bore at this level via a fracture network within dolerite.

This has the overall influence of reducing the modelled heat flow iin the base of the well to **63.3±1.6 mW/m$^2$**. This value is inconsistent with regional trends and given the complexities of heating processes within this bore, it is recommended that lowest conductivity values should only be considered when expressing surface heat flow. This would estimate surface heat flow at **96.0±2.5 mW/m$^2$**, consistent with other wells modelled in this report.

This zone of significant heat addition coincides with an area of extreme fracturing and faulting within the core where upto three (?reverse) faults were noted during inspection. The location of fractures and faults is shown as pink polygons on figure 4.

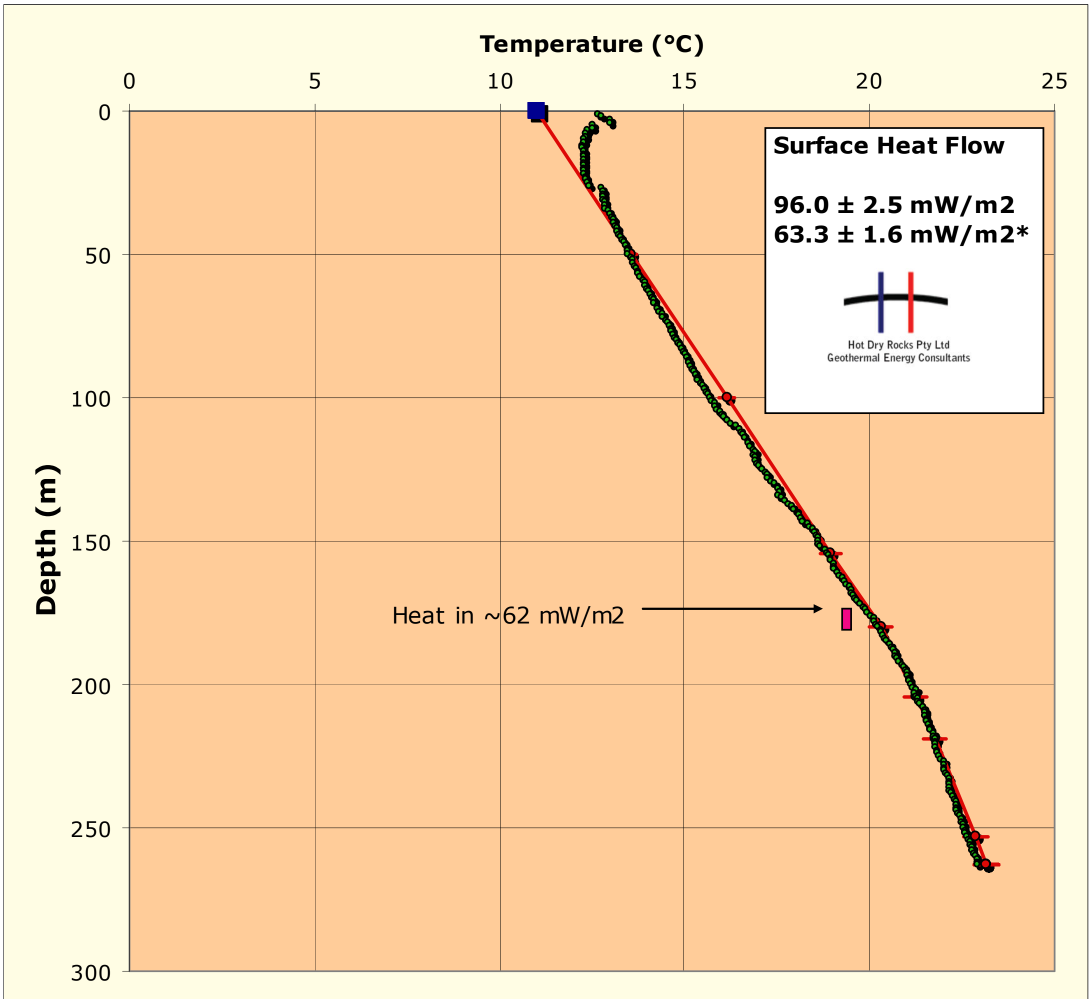


**Figure 4**. Tooms-1 – modelled surface heat flow based on rock thermal conductivity data (red points) and precision temperature logs (green line). Upper divergence in temperatures is due to air and cooled water at the top of the bore. A significant amount of heat ~62 mW/m2 may be added to the bore between 154-204m depth, possibly due to the flow of warm water through a fracture network. *This possible convective heat flow has perturbed the modelled heat flow in the base of the well (63 mW/m2). However the real surface heat flow is probably about 96 mW/m2 based on the deepest conductivity data. Pink polygons denote zones of extensive fracturing and faulting noted in core.

# 4.0 Comparative interpretation of heat flow data

Modelled surface heat flow values for SEL26/2005 range between 92 and 96mW/$m^2$. These Tasmanian data are within the range of values commonly reported in many parts of the Cooper Basin, South Australia (Beardsmore, 2005 & McLaren et al, 2003)[1] and recently reported for the Adelaide Fold and Thrust Belt (South Australia).

Figure 5 illustrates the distribution of heat flow data modelled in this report (orange polygon) with respect to those values presently available for all of Australia within the *Global Heat Flow Database*. Values modelled in this report for SEL26/2005 are all within the top 17% of heat flow values for Australia in the *Global Heat Flow Database*.

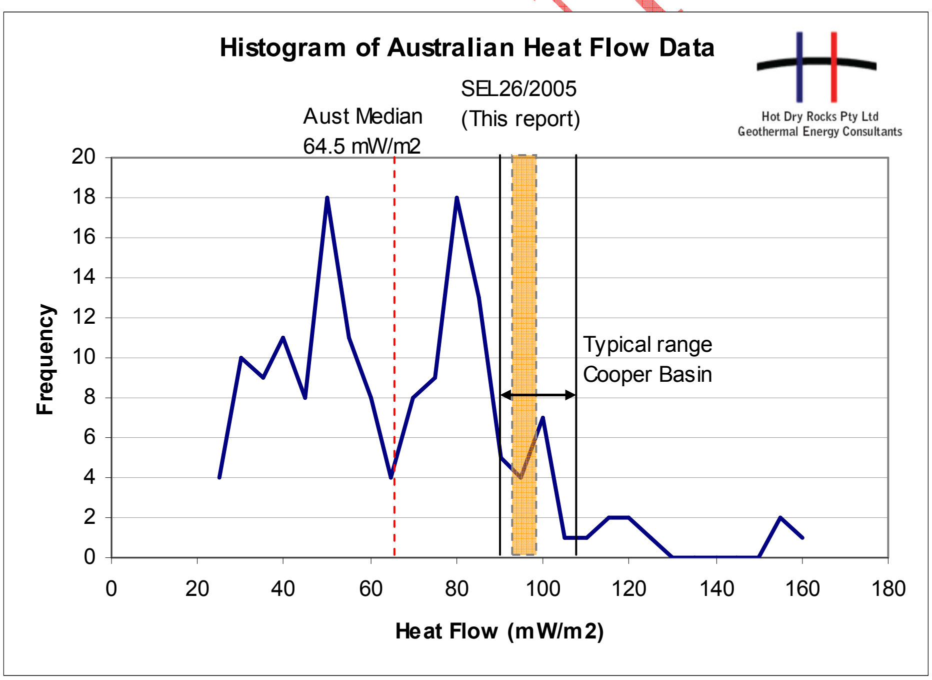


**Figure 5**. Distribution of Australian heat flow data from the Global Heat Flow Database showing relative position of values commonly reported for the Cooper Basin (South Australia) and values modelled for SEL26/2005 (Tasmania) in this study (orange polygon).

[1] **Beardsmore, G.R.** (2005). Thermal modeling of the hot dry rock geothermal resources beneath GE99 in the Cooper Basin, South Australia. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey. CD-Rom.

[2] **McLaren S, Sandiford M, Hand M, Neumann N, Wyborn L and Bastrakova I** (2003). The hot southern continent: heat flow and heat production in Australian Proterozoic terranes. Geological Society of Australia Special Publication 22, pp 151-161.

## 5.0 Conclusions and recommendations

Modelled surface heat flow values for four shallow wells in SEL26/2005 are generally consistent and range between 92 and 96mW/$m^2$. These values are similar to those commonly reported for parts of the Cooper Basin and Adelaide Fold and Thrust Belt (South Australia).

The following recommendations are presented for the clients consideration:-

- Continued conductivity measurement, precision temperature logging and heat flow modelling for other parts of SEL26/2005 to increase the density of available quality heat flow data.
- Thermal conductivity measurement of selected wells in the 0-150m interval so as to better constrain conductivity-temperature relationships for the upper well section and define advective processes (if present).
- Deep 1D heat flow modelling of selected areas based on data available in this report and from deeper stratigraphy defined from regional reflection seismic data and/or regional cross-section and mapping data. This should provide preliminary estimates of projected temperature at depth.

**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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# Heat flow modelling of selected wells in SEL26/2005, Tasmania

Prepared for KUTh Energy Ltd (KEN)

Date 17 JUL 2008 Final

Gareth Cooper & Ben Waining

# Executive summary

Four (4) shallow wells in SEL26/2005 (Tasmania) were measured by Hot Dry Rocks Pty Ltd (HDRPL) for equilibrated downhole temperature. Core from the same wells was sampled and measured for rock thermal conductivity. Temperature and conductivity data have been combined using HDRPLs 1D Heat Flow Modelling Software to determine vertical heat flow within each well.

The resulting surface heat flows for each well are summarised in the table below:-

| **Well** | Temple Bar-1 | Tower Hill-1 | Epping-1 | Ben Lomond-1 |
|---|---|---|---|---|
| **Modelled Heat Flow (mW/m$^2$)** | 87.0 ± 1.9 | 83.0 ± 1.0 | 92.0 ± 0.6 (base)<br>62.0 ± 0.4 (top) | 97.0 ± 2.3 |



Three of the wells have elevated surface heat flow (ranging from 83–97 mW/m$^2$). Epping-1 shows evidence of heat removal at a depth between 225 m and 250 m, with modelled heat flow of 92 mW/m$^2$ in the deepest section of the hole.

The heat flow modelled for Temple Bar 1, Ben Lomond 1 and the deepest section of Epping 1 is in the range of values reported for parts of the Cooper Basin and the Adelaide Fold and Thrust Belt (South Australia). Heat flow values for all four wells (excluding the upper value for Epping-1) fall within the upper 25% of heat flow values recorded for Australia in the *Global Heat Flow Database*.

**Disclaimer**
The information and opinions in this report have been generated to the best ability of the author, and Hot Dry Rocks Pty Ltd hope they may be of assistance to you. However, neither the author nor any other employee of Hot Dry Rocks Pty Ltd guarantees that the report is without flaw or is wholly appropriate for your particular purposes, and therefore we disclaim all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

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# 1.0 Introduction

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SEL26/2005 is located in eastern Tasmania and extends from George Town in the north of the state to Hobart in the south. As part of its work program, KEN is undertaking a shallow drilling program to define heat flow variation within its tenement. This report provides modelled heat flow values for the following shallow wells:-

- Temple Bar 1
- Tower Hill 1
- Epping 1
- Ben Lomond 1

Heat flow models described in this report incorporate rock thermal conductivity measurements and calibrated precision temperature logs recently undertaken by HDRPL for the same wells.



# 2.0 Introduction to heat flow

Heat flow is a power unit expressed at surface ($mW/m^2$) and is a function 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 a region is usually 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 highly 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 a product of temperature gradient and rock thermal conductivity and is therefore not directly measured. Consequently, the measurement of heat flow is a precision skill that requires a detailed understanding of physical conditions in the bore and the physical properties of the rocks; including potential advective processes that may influence bore temperature (such as ground water flow) and the temperature dependence of conductivity.

HDRPL utilises its own 1D Heat Flow Modelling Software to determine heat flow from measured values. Forward modelled temperature distribution with depth, incorporating advective influences and temperature dependence of thermal conductivity, is compared against the observed temperature profile within a bore. The precise vertical heat flow value is determined that best fits the observed profile. The results of 1D heat flow modelling should be treated with caution when extrapolating over lateral distances, because heat refraction can lead to significant variation in vertical heart flow over relatively short lateral distances. Detailed 2D or 3D modelling is recommended if such effects are suspected.

# 3.0 Results of heat flow models

## *3.1 Summary of modelled surface heat flows*

A summary of modelled surface heat flow results is shown in table 1. Sections below describe each model in detail.

**Table 1.** Summary of modelled surface heat flows for shallow wells in SEL26/2005

| **Well** | Temple Bar 1 | Tower Hill 1 | Epping 1 | Ben Lomond 1 |
|---|---|---|---|---|
| **Modelled Heat Flow ($mW/m^2$)** | 87.0 ± 1.9 | 83.0 ± 1.0 | 92.0 ± 0.6 (base)<br>62.0 ± 0.4 (top) | 97.0 ± 2.3 |

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### *3.2 Temple Bar 1*

The heat flow model for Temple Bar 1 (Fig. 1) illustrates a very good fit between the observed and predicted temperature data. The well only intersected Jurassic dolerite with rock thermal conductivities ranging from 2.28–2.49 W/mK. The conductive vertical heat flow is **87.0 ± 1.9 mW/m$^2$** over the conductivity-constrained interval (approximately 150 m – 300 m).

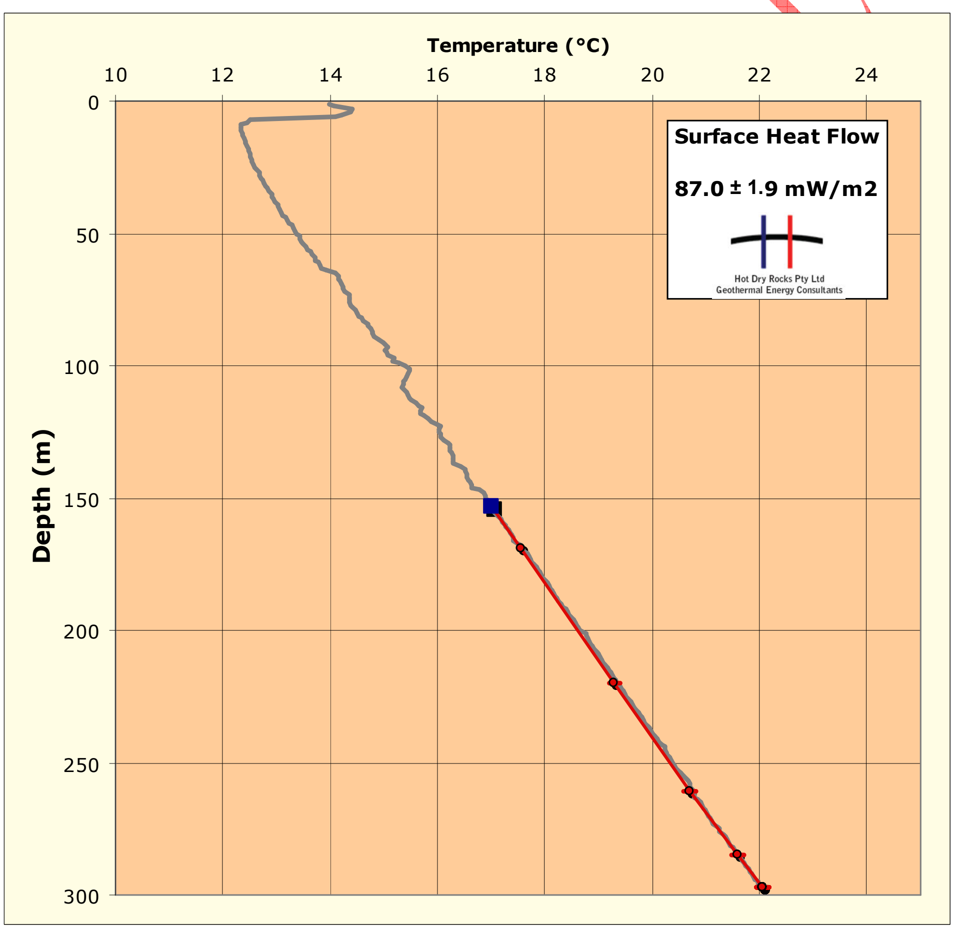


**Figure 1**. Temple Bar 1 – conductive heat flow modelled from rock thermal conductivity data and precision temperature log (grey line). Red line is the modelled temperature profile for the stated heat flow. Divergence in the temperature profile in the shallow section of the bore is due to air and cooled water at the top of the bore.

## *3.3 Tower Hill 1*

The heat flow model for Tower Hill 1 (Fig.2) illustrates an excellent fit between the observed and predicted temperature data. The well only intersected Ordovician Mathinna Supergroup rocks with a high angle foliation and rock thermal conductivities ranging from 4.06–5.23 W/mK. The modelled conductive vertical heat flow is **83.0 ± 1.0 mW/m$^2$** over the conductivity-constrained interval (approximately 160 m – 260 m).

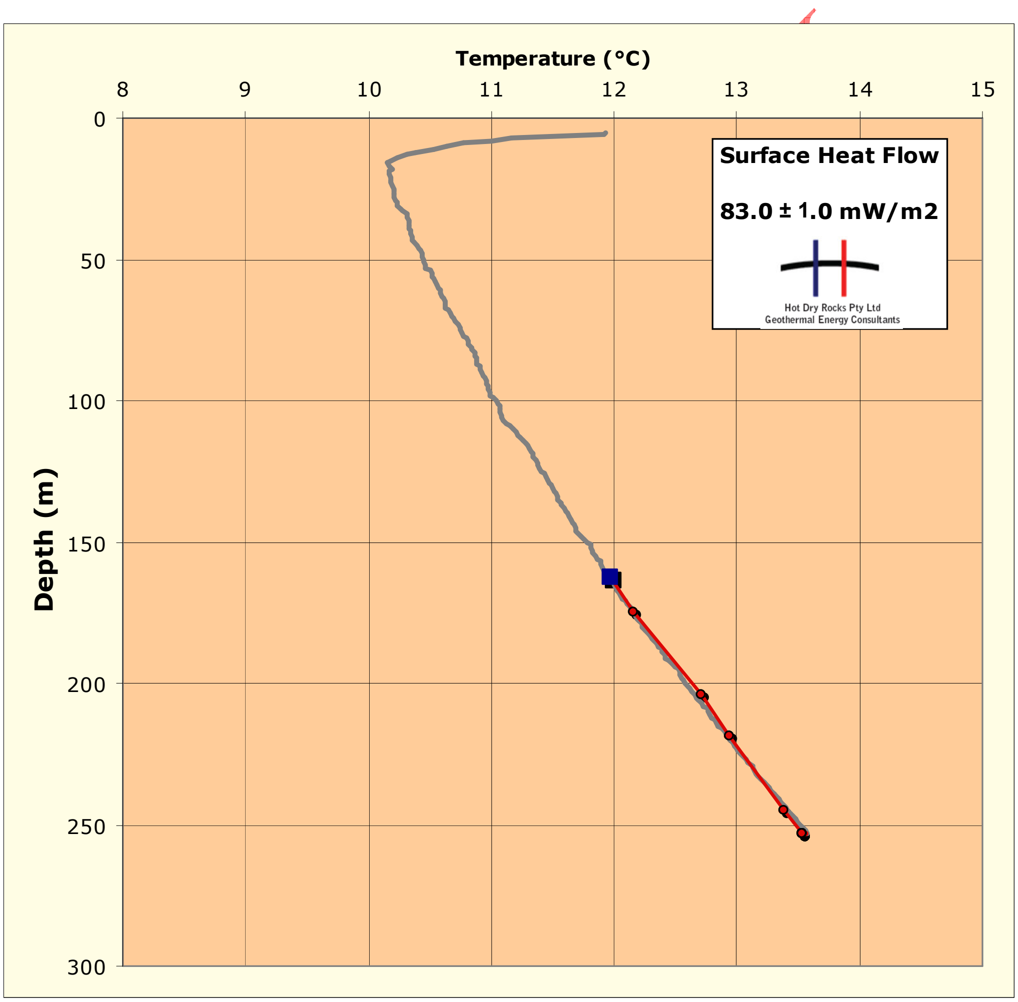


**Figure 2**. Tower Hill 1 – conductive heat flow modelled from rock thermal conductivity data and precision temperature log (grey line). Red line is the modelled temperature profile for the stated heat flow. Divergence in the temperature profile in the shallow section of the bore is due to air and cooled water at the top of the bore.

### *3.4 Epping 1*

An excellent fit could only be achieved between measured and modelled temperature profiles in Epping 1 (Fig.3) by incorporating an advective component of heat transfer within the model. The well only intersected Jurassic dolerite with rock thermal conductivities ranging from 1.87–2.18 W/mK. Modelling suggests that heat may be removed from the vertical profile at a rate of approximately 30 $mW/m^2$ between about 225 m and 250 m. These observations suggest that relatively cool water may be passing through the bore within that depth interval. A possible source of the water is unconstrained, although the depth indicates a possible meteoric origin. The modelled surface conductive vertical heat flow is **62 ± 0.4 $mW/m^2$** over the conductivity-constrained interval between about 145 m – 225 m. Between about 250 m and the base of the conductivity-constrained interval (289 m), however, conductive vertical heat flow is **92 ± 0.6 $mW/m^2$**. It could be argued that the value for the deeper portion of the bore is more likely to represent the background heat flow at that location.

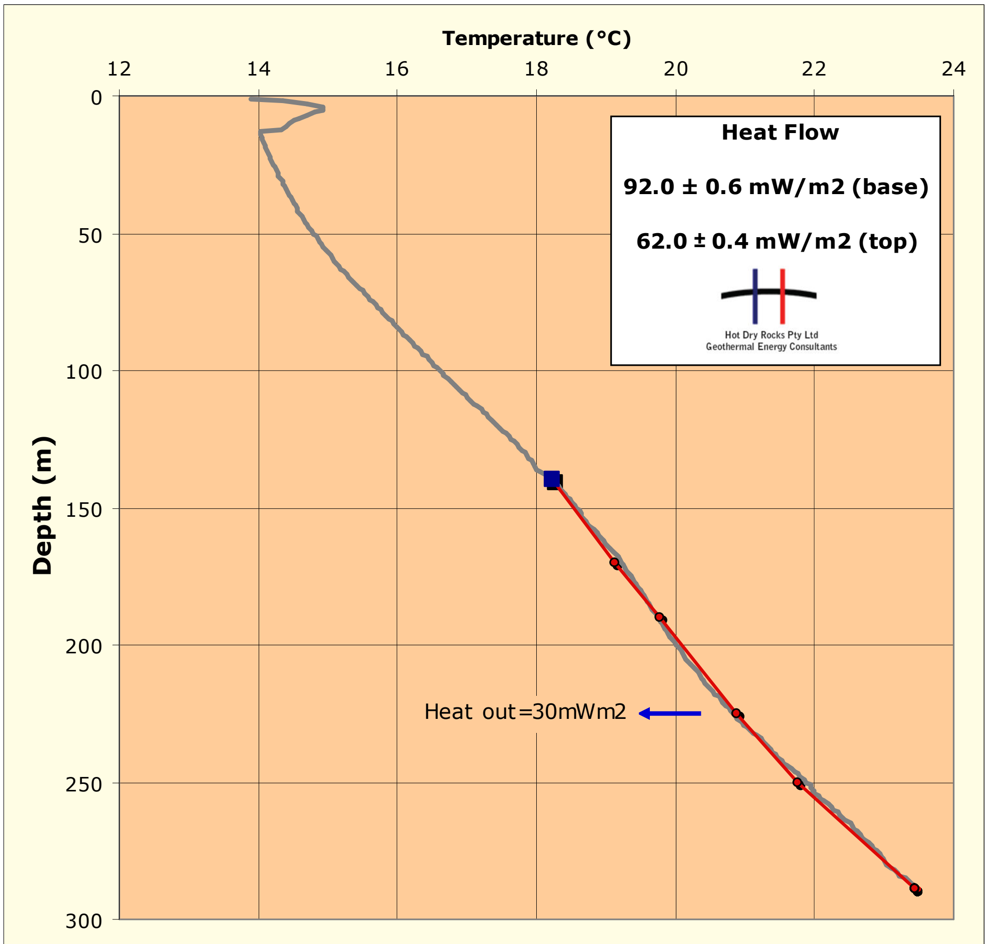


**Figure 3**. Epping-1 – conductive heat flow modelled from rock thermal conductivity data and precision temperature log (grey line). Red line is the modelled temperature profile for the stated heat flow. Divergence in the temperature profile in the shallow section of the bore is due to air and cooled water at the top of the bore. Temperature data suggest the removal of heat at a rate of 30 mW/m$^2$ at a depth between 225 m and 250 m, possibly via water passing through fracture networks.

### *3.5 Ben Lomond 1*

The heat flow model for Ben Lomond 1 (Fig.4) illustrates a good fit between the observed and predicted temperature data. The well only intersected Ordovician Mathinna Supergroup rocks with a high angle foliation and rock thermal conductivities ranging from 3.87–4.41 W/mK. The modelled conductive vertical heat flow is **97 ± 2.3 mW/m$^2$** over the conductivity-constrained interval (approximately 135 m – 275 m).

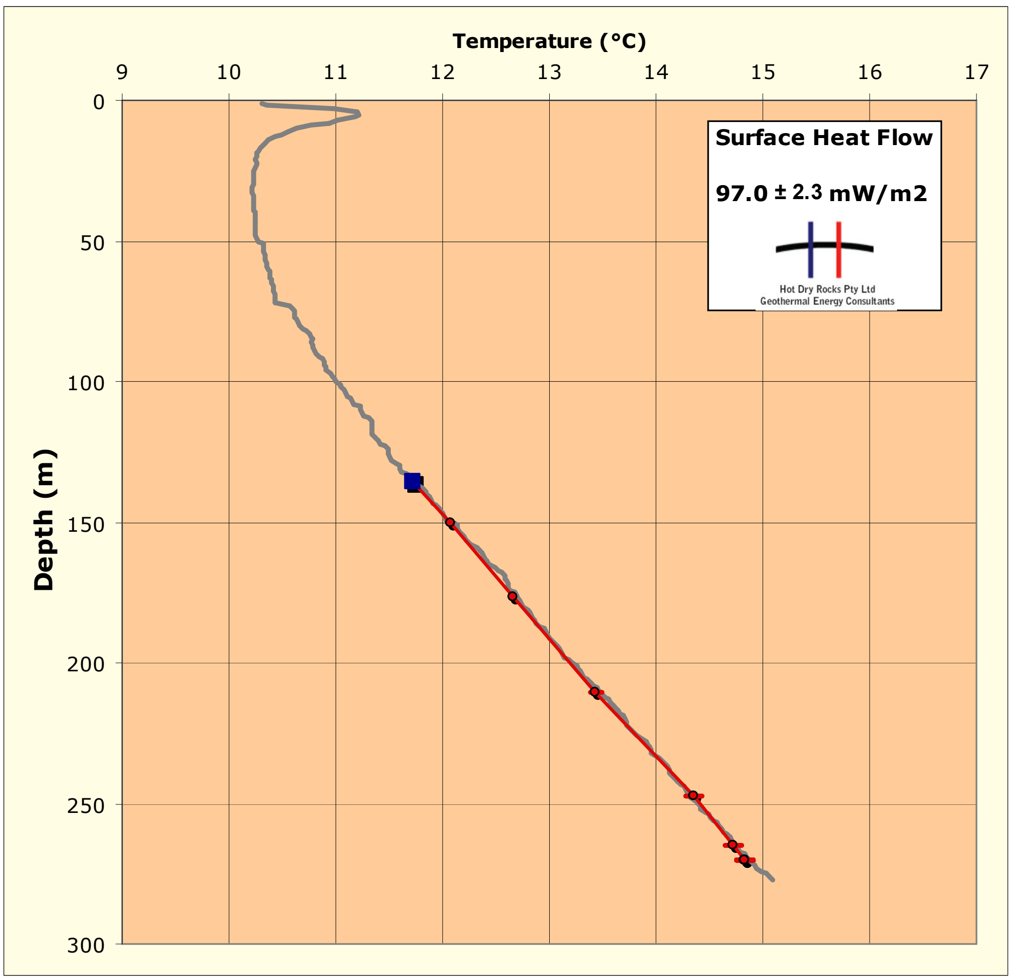


**Figure 4**. Ben Lomond – conductive heat flow modelled from rock thermal conductivity data and precision temperature log (grey line). Red line is the modelled temperature profile for the stated heat flow. Divergence in the temperature profile in the shallow section of the bore is due to air and cooled water at the top of the bore.

## 4.0 Comparative interpretation of heat flow data

Modelled surface heat flow values for the four selected wells in SEL26/2005 range from 62 to 97 $mW/m^2$. Of these wells, the values for Temple Bar 1, Ben Lomond 1 and the deeper section of Epping 1 are within the range of values commonly reported in parts of the Cooper Basin, South Australia (Beardsmore, 2005[1], McLaren et al., 2003[2]) and recently reported for the Adelaide Fold and Thrust Belt (South Australia).

Figure 5 illustrates the distribution of heat flow data modelled in this report (orange polygon) with respect to those values presently available for all of Australia within the *Global Heat Flow Database*. Values modelled in this report for the four selected wells (except for the upper value for Epping-1) in SEL26/2005 are all within the top 25% of heat flow values for Australia in the *Global Heat Flow Database*.

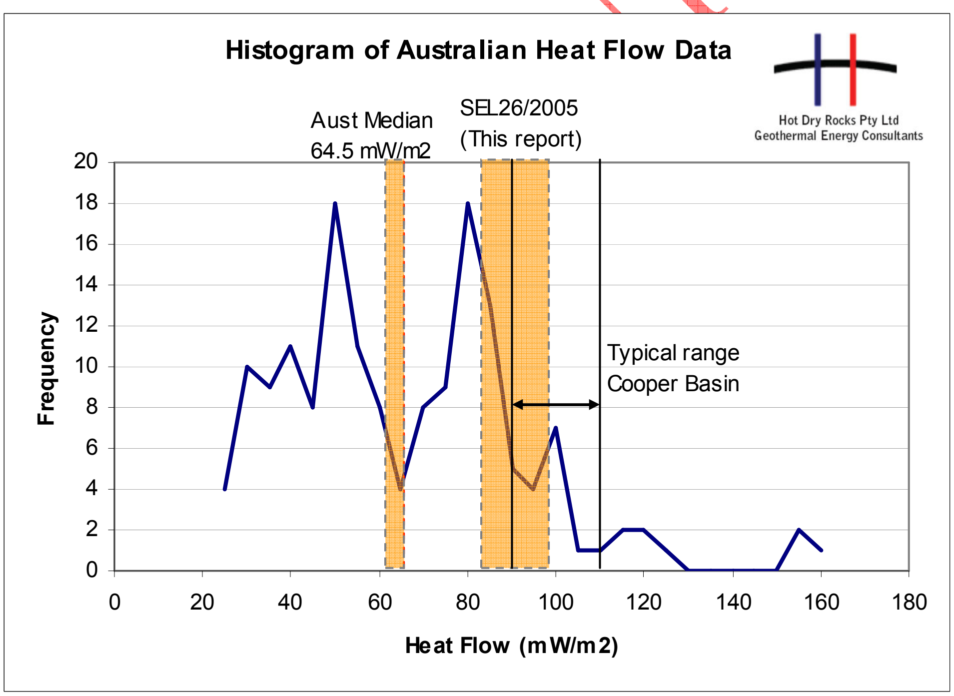


**Figure 5**. Distribution of Australian heat flow data from the Global Heat Flow Database showing relative position of values commonly reported for the Cooper Basin (South Australia) and values modelled for the four selected wells in SEL26/2005 (Tasmania) in this study (orange polygon).

[1] **Beardsmore, G.R.** (2005). Thermal modeling of the hot dry rock geothermal resources beneath GE99 in the Cooper Basin, South Australia. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey. CD-Rom.

[2] **McLaren S, Sandiford M, Hand M, Neumann N, Wyborn L and Bastrakova I** (2003). The hot southern continent: heat flow and heat production in Australian Proterozoic terranes. Geological Society of Australia Special Publication 22, pp 151-161.

## 5.0 Conclusions and recommendations

Modelled surface heat flow values for the four selected shallow wells in SEL26/2005 range between 62 and 97 mW/m$^2$. Two of these values are comparable to the range of heat flow values reported for parts of the Cooper Basin and Adelaide Fold and Thrust Belt (South Australia). In addition, apparent conductive vertical heat flow in the deeper portion of Epping 1 is also greater than 90 mW/m$^2$.

The following recommendations are presented for the client's consideration:-

- Continue conductivity measurement, precision temperature logging and heat flow modelling for other parts of SEL26/2005 to increase the spatial density of available quality heat flow data.
- Measure thermal conductivity of selected wells in the 0–150 m interval to better constrain conductivity-temperature relationships for the upper well sections and identify advective processes (if present).
- Model deep 1D heat flow projections of selected areas based on data presented in this and earlier reports and stratigraphy derived from regional reflection seismic data and/or geological cross-sections and maps. This would provide preliminary projections of temperature at depth.
- Investigate the impact on thermal conductivity of the varying angle of the dominant foliation in the Mathinna Supergroup. Sub-horizontal foliation could provide significantly greater thermal insulation.