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Heat Flow Determinations for the Australian Continent

Release 4

Gerner, E.J., Kirkby, A.L. and Ayling B.F.

Record

2012/75

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APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Heat Flow Determinations for the Australian Continent:

Release 4

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by

Gerner, E.J., Kirkby, A.L. and Ayling, B.F.

Australian Government
Geoscience Australia

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Contents

Executive Summary

Heat flow data across Australia are sparse, with around 150 publicly-available data-points. The heat flow data are unevenly distributed and most of it comes from studies undertaken by the Bureau of Mineral Resources (BMR) and the Research School Earth Sciences at the Australian National University in the 1960s and 1970s. Geoscience Australia has continued work started under the federally-funded Onshore Energy Security Program (OESP), collecting data to add to the heat flow coverage of the continent.

This report presents temperature, natural gamma and thermal conductivity data for 12 boreholes across Australia. Temperature logging was performed down hole with temperatures recorded at intervals less than 20 cm. Samples of drill core were taken from each well and measured for thermal conductivity at Geoscience Australia.

One dimensional, conductive heat flow models for the boreholes are presented here. These new determinations will add to the 41 already released by Geoscience Australia under the OESP, totalling 53 determinations added to the Australian continental heat flow dataset since 2007.

Introduction

As part of the Australian Government-funded Onshore Energy Security Program (Geoscience Australia, 2011), Geoscience Australia (GA) released 41 heat flow determinations (Kirkby and Gerner, 2010; Jones et al., 2011, Weber et al., 2011). After the completion of the Onshore Energy Security Program in June 2011, heat flow data collection has continued and this record presents an additional 12 heat flow determinations (Table 1) bringing the total to 53 new heat flow determinations for the Australian continent. This is an increase of more than 40% in the publicly-available heat flow points for Australia since 2007. The locations of the heat flow determinations produced by GA are shown in **Figure 1**:

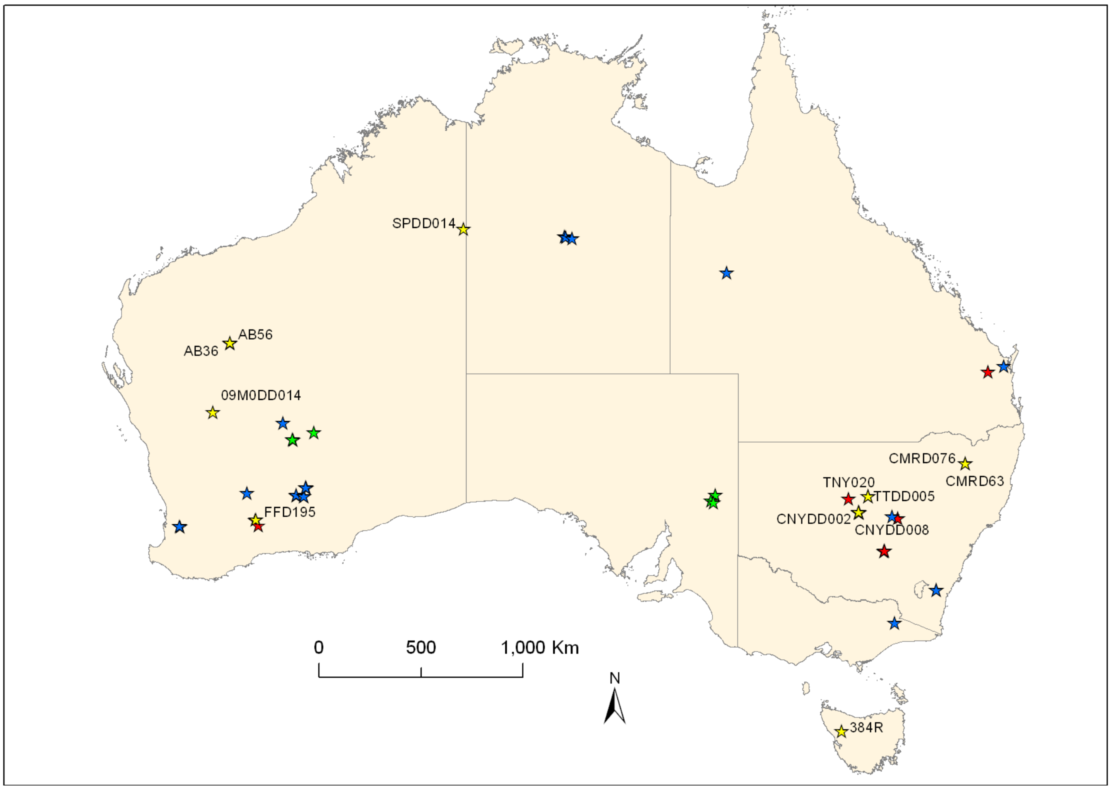

Figure 1: *Heat flow determinations made by Geoscience Australia under the Onshore Energy Security Program. Red points are from Release 1 (Kirkby and Gerner, 2010), green points are from Release 2 (Jones et al., 2011), blue points are from Release 3 (Weber et al. 2011), and yellow points are from Release 4 (this report). (Note: Only the new determinations are labelled and at this scale, some data points appear on top of one another).*

Table 1: *Location, depth, dip and heat flow determinations of the 12 wells discussed in this report. UE means the well is un-equilibrated and thus the heat flow should be used with caution. A spreadsheet version of this table is provided in Appendix 1. (UE = Unequilibrated)*

Well Name	Region	Latitude (GDA94)	Longitude (GDA94)	Depth (m)		DIP (-°)	Heat Flow (mW/m^2)
				Logged Depth	True Vertical		
09MODD014	Murchison, WA	-27.689125	117.832461	410	358	-60	39.0 ±2.5
384R	North West Tasmania	-41.749722	145.563056	1700	1691	-85	82 ±3 (UE)
AB36	Gascoyne, WA	-24.645754	118.582179	820	791	-77	89 ±3
AB56	Gascoyne, WA	-24.643624	118.584115	755	695	-67	86 ±3
CMRD063	North East NSW	-29.95211	151.023254	396	369	-66	77 ±3
CMRD076	North East NSW	-29.951704	151.023239	533	518	-73	79.0 ±1.5
CNYDD002	Central NSW	-32.108147	146.320404	658	620	-75	72.5 ±3.5
CNYDD008	Central NSW	-32.109669	146.331711	657	596	-65	51 ±3
FFD195	Southern Yilgarn, WA	-32.42308	119.706192	800	753	-72	34.5 ±4.0
SPDD0014	Tanami, WA	-19.585498	128.867539	349	301	-60	43 ±2
TNY020	Central NSW	-32.109108	146.326935	578	536	-68	53.0 ±2.5
TTDD005	Central NSW	-31.396683	146.734848	1208	1195	-80	52 ±9

Input Data

TEMPERATURE LOGS

Wells were logged by GA using either the Auslog A626 combined temperature/gamma probe or the Auslog A621 temperature probe. Both probes have a temperature precision of 0.007 ºC and can measure temperatures up to 70º C. The probe is connected to a winch with 1800 m of four-conductor cable, which, with the exception of drillhole 384R, was sufficient to log all wells reported here to maximum depth or to where blockages were encountered.

The Auslog DLS5 digital logging system connects the tool to a laptop computer. Wellvision software was used to record the data. The temperature (and gamma) readings were recorded down the well at a speed of approximately five metres per minute and the probe is set to take measurements every 20 cm, regardless of speed. GA has experimented with sampling intervals and found one sample every 20 cm to be optimum for heat flow determinations.

Wells were logged as long as possible after drilling was completed to increase the chances of equilibrium being reached before logging. In some cases, due to accessibility constraints, wells were logged within days of drilling and it is very unlikely that equilibrium had been reached before logging. Where this is the case it has been noted in the results.

The temperature logs were converted from measured depth (length of drill hole) to true vertical depth (perpendicular depth from the surface) using survey information provided by the companies that drilled each well (see Table 1). The temperature data were then smoothed using a three point running average. The raw temperature files can be found in electronic Appendix 2.

GAMMA LOGS

Nine of the twelve wells presented here were logged using the Auslog A626 probe, which collects natural gamma data in addition to the temperature data. The Auslog A621 temperature probe, which measures temperature only, was used when the A626 probe required maintenance. The natural gamma data were collected at the same depth intervals down the well as the temperature measurements. The natural gamma logs were converted from measured depth to true vertical depth and smoothed with a three point running average. The raw gamma logs can be found in electronic Appendix 2.

THERMAL CONDUCTIVITY MEASUREMENTS

Core specimens were collected from each well for thermal conductivity analyses. Where possible, specimens approximately 15-20 cm in length were collected at intervals of 50-100 m down each well. Sampling was guided by lithology logs where available, with the aim of sampling each lithology in the well while avoiding mineralised zones. This was not possible in all wells due to a variety of limitations on sampling resulting in less-than-ideal sample distribution. In these cases the heat flow was determined making the best of the data available.

Core specimens were analysed for thermal conductivity by Geoscience Australia (GA). Each core specimen was sub-sampled to create up to three discs. The discs were subsequently cut to ensure that the top and bottom faces were parallel and then polished, prior to measurement. The discs were measured using a divided bar apparatus (Anter Unitherm 2022). Where multiple discs were available, the harmonic mean and standard deviation of the thermal conductivity were computed. Details of the samples measured for this study are provided in Appendix 3.

All samples were measured in a saturated state at a temperature of 30 ± 3 ºC. In order to saturate the samples, they were first evacuated under a >95 % vacuum for 3 - 4 hours to remove air from the pore spaces. Discs were then submerged in water for 12 hours under vacuum and returned to atmospheric pressure. Discs were left in the water at atmospheric pressure until just prior to thermal conductivity measurement.

LITHOLOGY LOGS

A number of companies provided lithology logs for their drill holes. Where available, the logs were used in conjunction with the measured thermal conductivities to assign thermal conductivity values to each lithology unit in the well. These extra thermal conductivity values provided additional constraints on the heat flow determinations.

WELL ORIENTATION DATA

For many wells the only orientation data provided to Geoscience Australia was the collar orientation. For these wells the depth correction could only be performed with this data. In other cases the orientation data for the full depth of the well was supplied, allowing a more accurate depth correction. The level of detail of the orientation survey can vary but it is most commonly recorded using single shot cameras at intervals varying from about 30 m to >100 m.

Heat Flow Calculation Method

Heat flow determinations were calculated using the following method after Kirkby and Gerner (2010).

1. Well orientation data (either orientation survey data or an assumed inclination based on the collar orientation) was used to correct the recorded logs and the depth of the samples taken to a true vertical depth. A thermal gradient log was calculated from the temperature log at either a 1 m or 2 m rolling interval.
2. The depth-corrected temperature log was visually inspected to select a conductive interval from the temperature log on which to undertake the heat flow determination. This conductive zone:
    a. avoids the near surface (which is likely to be affected by seasonal variations in temperature); and
    b. avoids sections of the log that appear to be influenced by significant advective heat flow.
3. The depth-corrected thermal conductivity values were plotted on the depth-corrected log to determine which values correspond to the above defined conductive zone.
4. The conductive zone described in point 2 was divided into sub-sections which could be characterised by the measured thermal gradients. Where available, the division of sub-sections was based on the supplied lithology logs with reference to the gradient and gamma logs. In the absence of lithology information, the sub-section boundaries were based on changes in the magnitude and character of the thermal gradient and gamma logs.
5. For wells in which the detailed lithology log indicated a repeating stratigraphy, it was possible to apply the measured thermal conductivity for one sample to other sub-sections that had been classified as the same lithology.
6. Thermal conductivity values, their errors and the sub-section boundaries were entered into a 1D conductive heat flow modelling spreadsheet. Modelling commenced at the top of the conductive section using the measured temperature at that point. From this point downward, the measured thermal conductivity values attributed to the sub-section were used with a constant heat flow value to predict the temperature at the base of each sub-section.
7. The predicted temperatures were then plotted with the temperature log and the heat flow value was adjusted until there was good agreement between the predicted temperature and the logged temperature.
8. Where it was difficult to achieve a fit with the data, the sub-section boundaries and the justification for each one was re-examined to see if there was cause to refine the positioning of each.
9. Finally, error bounds were established to provide an indication of the confidence in each heat flow determination. The errors are due to the uncertainty (standard deviation) of the input thermal conductivity values. In previous reports the uncertainty due to the positioning of the sub-section boundaries was determined. As none of the sub-section boundaries were defined solely on the position of the thermal conductivity samples this step has been excluded. The uncertainty in thermal conductivity values was used to determine the upper bound and lower bound heat flow values as follows:
    a. With the standard deviations of the thermal conductivity measurements established, the constant heat flow was adjusted until each of the bounding errors no longer fit the temperature log.
    b. In cases where the error was greater in one direction than the other the largest error was used.
    c. The error is then the difference between the initial heat flow determined (in point 5) and the highest and lowest heat flow values determined from 9a and 9b.

Results

09MODD014

09MODD014 is located near Cue in the Murchison Province of Western Australia. Geologically the Murchison Province is within the Archean Yilgarn Craton. The well was drilled by Silver Lake Resources and logged by GA using the combined temperature/gamma probe (Auslog A626) to a depth of 410 m (vertical depth 358 m).

The temperature profile is shown in **Figure 2** and from this the conductive zone has been defined as 60 m to 195 m depth. Selection of this zone was restricted by the availability of thermal conductivity measurements. It is likely that this section of the log is influenced by surface effects, so while the level of uncertainty in the heat flow determination is comparatively low, it should be used with this knowledge in mind. In addition it can be seen that the temperature log has some sizeable steps in it which may be indicative of fluid movement through the hole.

A heat flow of $39 \pm 2.5\ mW/m^2$ has been determined for this well. Section boundaries were determined using the character of the calculated gradient log and the gamma log (Table 2). Three thermal conductivity samples were collected from this well, however it was only possible to prepare and measure two of the samples, hence the restricted depth of the section of the log on which the heat flow determination was based.

Table 2: *Samples, thermal conductivity values and sub-sections boundaries for well 09MODD014.*

Sample Number	True Vertical Depth of Sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122318	86.5	Dolerite, minor alteration	3.34	0.20	60 - 100	Gamma and Gradient Log character
2122319	176.2	Schist, sulphides present	3.61	0.13	100 - 195	Gamma and Gradient Log character

The modelled temperature data is plotted along with the measured temperature log in **Figure 3**. There is good agreement between the measured and modelled data, however with only two conductivity measurements (both from relatively shallow depths) the level of confidence in the determination is low. The error in the heat flow determination is primarily due to the uncertainty in the thermal conductivity measurements, as with only two sections over a short section of the log, changes to the boundary position made little difference.

There are three other heat flow determinations within 100 km of this location. These determinations are shown in **Table 3**. There is good agreement with the closest published heat flow determination, which is near Cue (Howard and Sass, 1964), but the other two, which are further away, are approximately 40% higher.

Table 3: *Previously-published heat flow determinations within 100 km of well 09MODD014.*

Name	Heat Flow mW/m^2	Distance and Direction from 09MODD014	Reference
Cue	39.8	26.4 km north	Howard and Sass, 1964
Mt Magnet	54.5	37.7 km south-southeast	Howard and Sass, 1964
Dalgaranga	52.0	73.8 km west-southwest	Cull, 1991

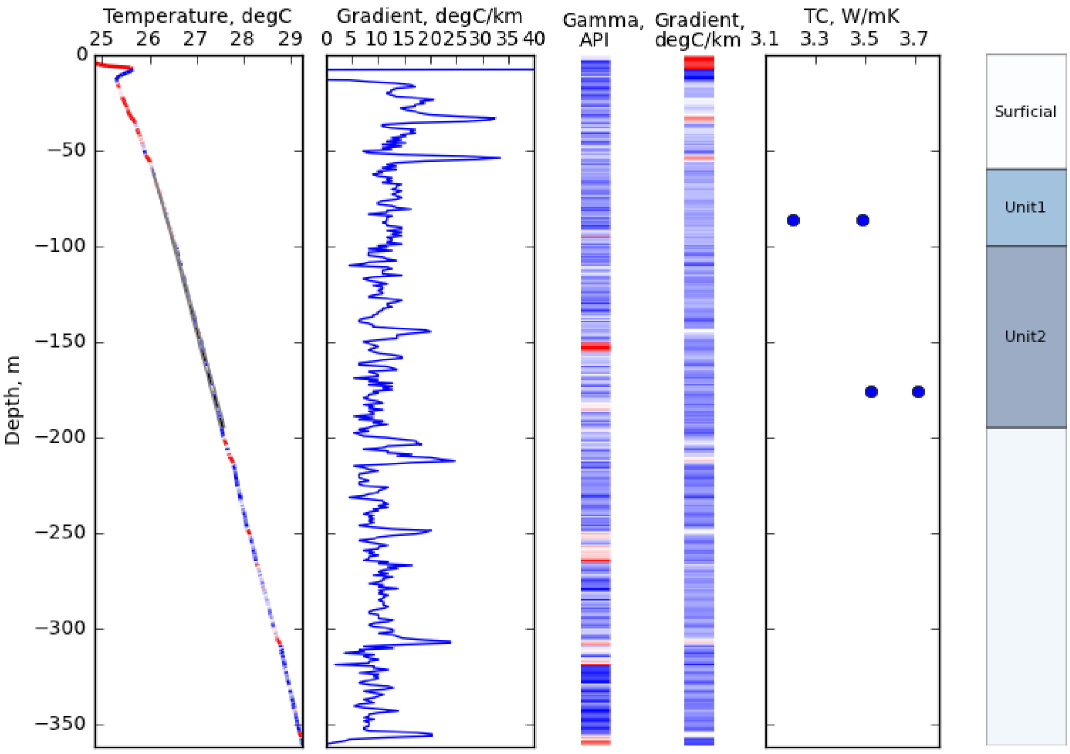

Figure 2: *Temperature log of well 09MODD014 with the calculated gradient. The gamma log is also displayed using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

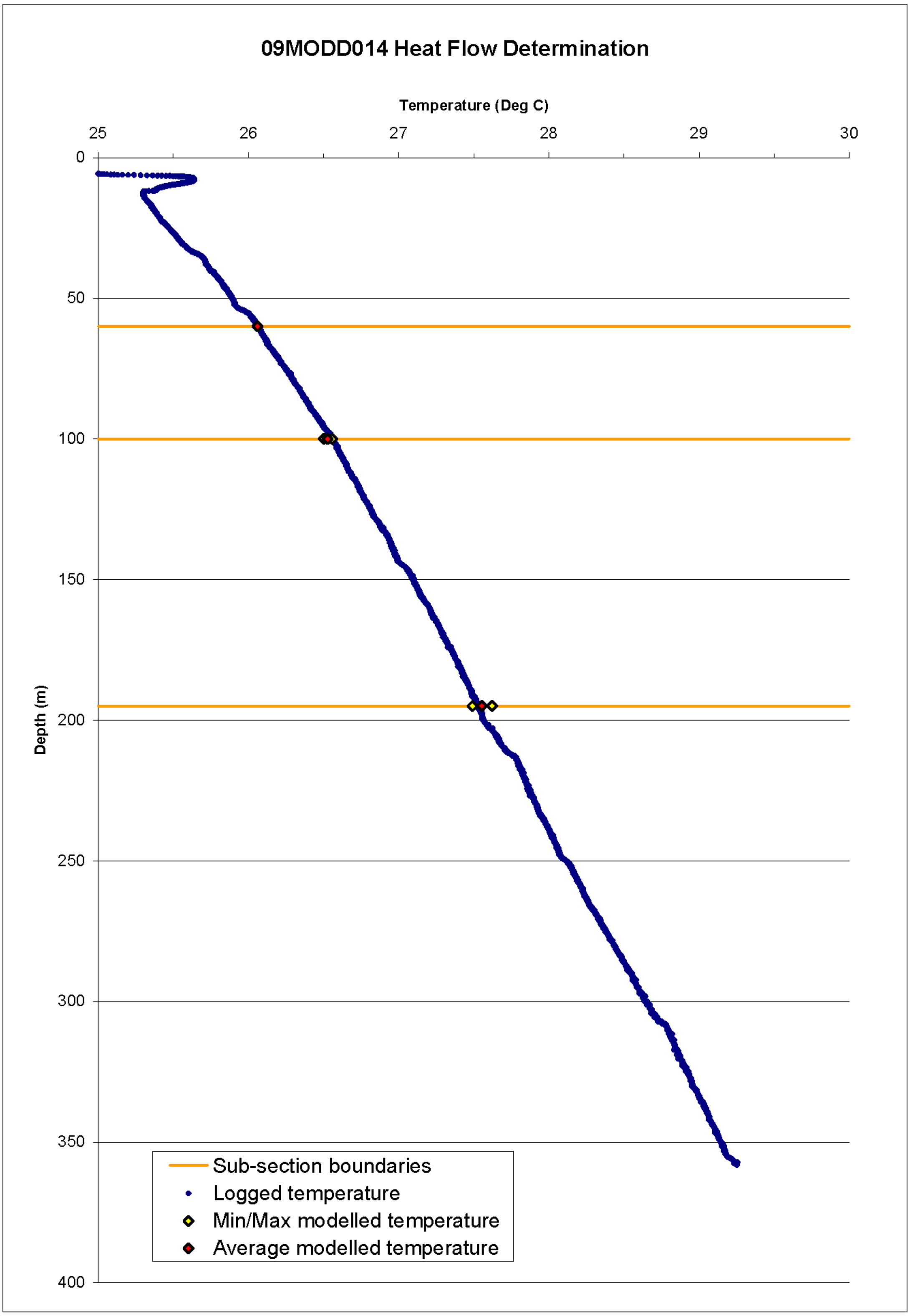

Figure 3: *Modelled and measured temperatures versus true vertical depth for 09MODD014. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

384R

384R is located near Rosebery in western Tasmania. The topography of the area is steep and rugged and the hills are heavily timbered. The well collar was located near the top of a hill; the well was drilled at a dip of -85° and personal communications with site geologists indicated that while it followed a slightly spiral path, the dip remained relatively constant. The well was drilled by Minmetals Resources Limited and logged by GA using the combined temperature/gamma probe (Auslog A626) to an estimated vertical depth of 1691 m. A lithology log was provided to GA.

The temperature profile is shown in **Figure 4** and from this the conductive zone has been defined between 700 m to 1200 m depth. This well was not equilibrated at the time of logging as it had only been completed three weeks before logging. The clearest expression of this can be seen in the log below 1200 m (see Figure 5).

A heat flow of $82 \pm 3\ mW/m^2$ has been determined for this well. Sub-section boundaries were constrained using the lithology log provided by Minmetals Resources and the character of the recorded gamma and calculated gradient logs (**Table 4**). Thermal conductivity samples for this well were collected in a slightly different fashion to the other wells in this report. Rather than one sample every 50-100 m, in this well three samples were typically collected over a ~5 m depth range every 100-150 m. From each of these samples, three discs were cut and measured. Upon inspection of the lithology log at each sample depth, it was established that the lithology was consistent and the harmonic mean of the nine measurements was thus used to produce a thermal conductivity value for the section. Samples were collected from nine depth ranges within the section of the well that was logged and were used to constrain the heat flow determination. One sample below the depth of logging was collected but not used in the determination.

Table 4: *Samples, thermal conductivity values and sub-sections boundaries for well 384R. N/A means that the sample was not used for the heat flow modelling.*

Sample Number	No. of discs	True vertical depth (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122272 - 2122274	9	303.94	Dacite, chlorite and hematite alteration	2.76	0.62	N/A	N/A
2122275-2122277	9	466.07	Dacite, chlorite and hematite alteration, veined	3.15	0.09	N/A	N/A
2122278-2122280	9	613.46	Fine to medium grained dacite, albite and sericite alteration, silicification	3.99	0.22	N/A	N/A
2122281	3	723.0	Medium to coarse grained, strongly foliated, volcaniclastic sandstone	3.31	0.09	700-760	Lith log with gamma and gradient
2122282 - 2122284	9	819.60	Foliated, medium to coarse-grained pumice breccia, chlorite and sericite alteration	3.55	0.12	760-911	Lith log with gamma and gradient

Sample Number	No. of discs	True vertical depth (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122285 - 2122287	9	992.20	Strongly foliated pumice breccia, contains sandstone, lithic and feldspar fragments	3.77	0.27	911 - 1000	Lith log with gamma and gradient
2122288 - 2122290	9	1168.30	Massive, hornblende, fine-grained dacite, silicified	3.11	0.12	1000-1190	Lith log with gamma and gradient
2122291 - 2122293	9	1344.30	Massive, hornblende, fine-grained dacite, silicified, veined	3.46	0.08	1190 - 1420	Lith log with gamma and gradient
2122294 - 2122296	9	1517.40	Coarse-grained, dacitic, pumice breccia, strongly silicified, sulfides present	3.71	0.22	1420 - 1693	Lith log
2122297 - 2122299	8	1691.10	Coarse-grained, dacitic pumice breccia, quartz/carbonate veins, strongly silicified	3.75	0.43	N/A	N/A (base of log)

The modelled temperature data is plotted along with the measured temperature log in Figure 5. There is good agreement between the measured and modelled data between 700 m and 1200 m. It was not possible to model the heat flow above 700 m. This may be due to the influence of the steep topography. Heat tends to refract away from the topographic highs towards the valleys, following the path of least resistance. Given that this well was collared near the top of a hill, a depth of approximately 700 m fits with the observed topographic variability in the area. There was no topographic correction applied to this heat flow determination. Below 1200 m two sections have been defined based on the lithology log, and it is inferred that these two sections would approximate the true geothermal gradient if the well were fully equilibrated. Because the section boundaries are well constrained with both lithology information and the gamma and gradient logs, the error in the heat flow determination is primarily due to the uncertainty in the thermal conductivity measurements. However when using this heat flow value the reader should be mindful of the fact that the well is not fully equilibrated and there has been no topographic correction applied to the heat flow calculation.

There is one previously-published heat flow determination made from two wells in the Rosebery area (Newstead and Beck, 1953): this determination was 104 mW/m^2. However, Newstead and Beck (1953) state that the two wells used for this determination had "peculiarities which make them unsatisfactory for calculation of heat flux". The peculiarities they list were the uncertain orientation of the well, the steep topography, the proximity to an ore body and the movement of groundwater as identified in the wells. The wells were also only 210 m and 274 m deep respectively. While this new well (384R) may still be affected by the factors mentioned above, the greater depth means that the section over which the heat flow has been determined is less likely to be influenced by the topography, as it is below the level of the valley beneath the hill from which it was drilled. However, further investigation would be required to confirm this.

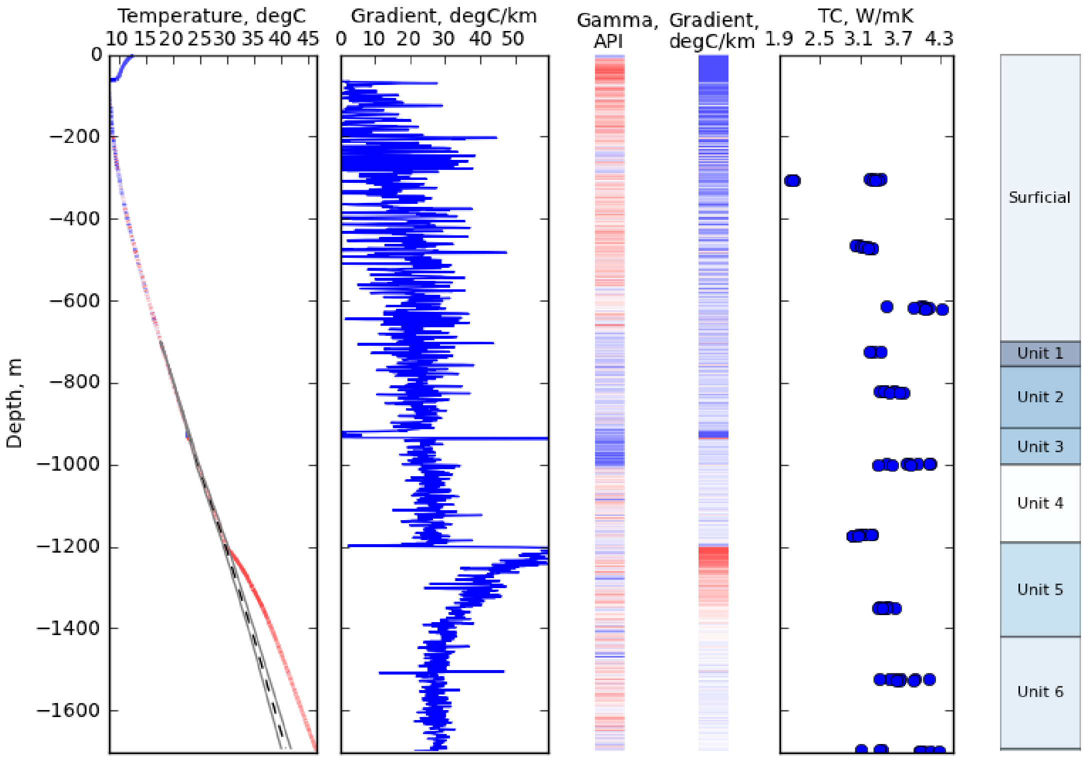

Figure 4: *Temperature log of well 384R with the calculated gradient. The gamma log is also displayed using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

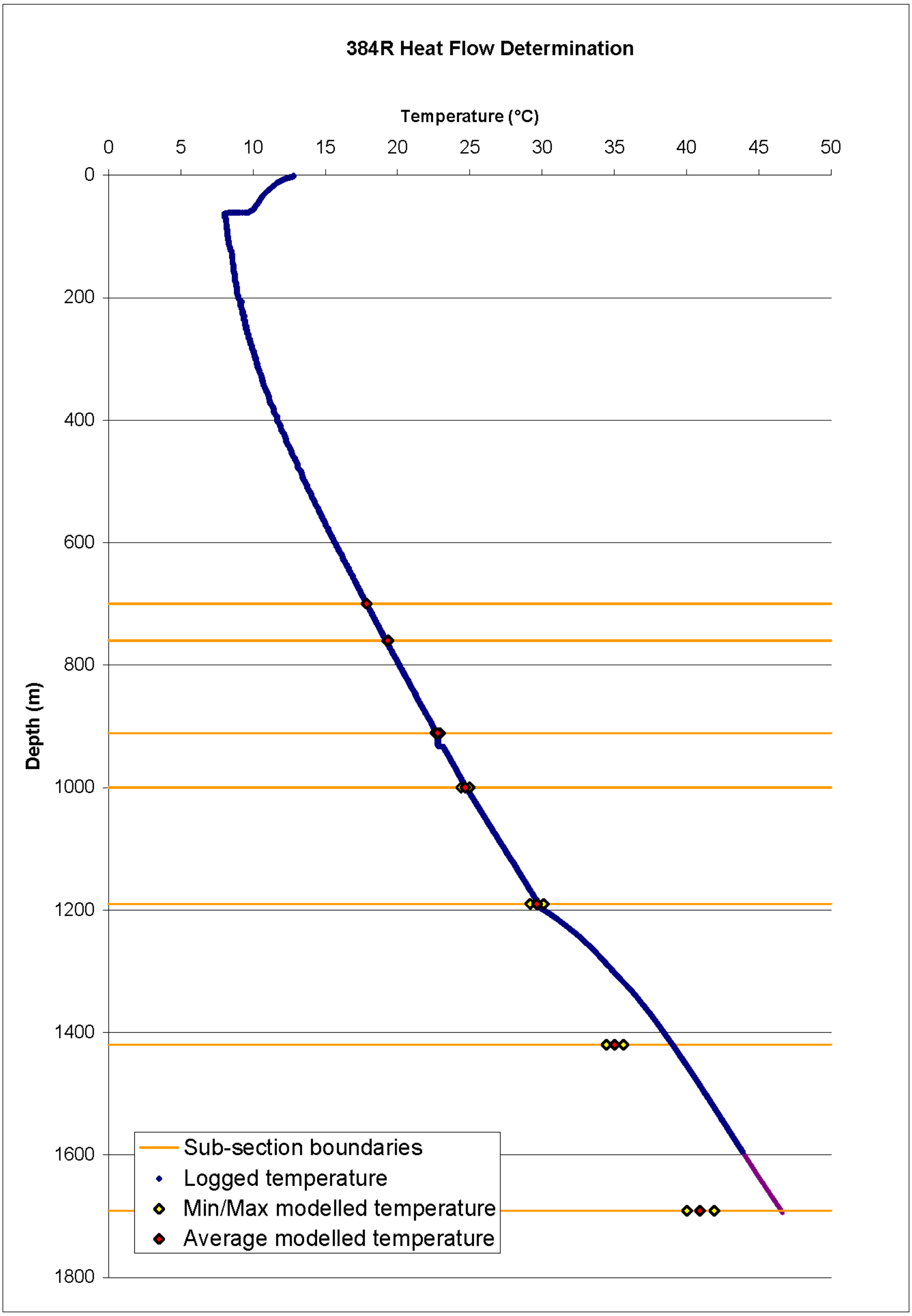

Figure 5: *Modelled and measured temperatures versus true vertical depth for 384R. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature). The noticeable notch in the temperature log at about 920 m is due to the logging tool momentarily becoming stuck in the well during logging.*

AB36

AB36 is located in the Mesoproterozoic Edmund Basin, approximately 200 km north of Meekatharra in Western Australia. The area is generally flat with sparse scrub and small trees. The well was drilled by Abra Mining Limited and logged by GA using the combined temperature/gamma probe (Auslog A626) to an estimated vertical depth of 791 m. AB36 is 472 m south-southwest of AB56.

The temperature profile is shown in **Figure 6** and from this the conductive zone has been defined between 170 m to 791 m depth. It was not possible to fit the data above this zone, likely due to surface effects disturbing the thermal conditions (see **Figure 7**).

A heat flow of $89 \pm 3\ mW/m^2$ has been determined for this well. In the absence of a lithology log the sub-section boundaries were constrained using the amplitude and character of the gamma and thermal gradient logs (**Table 5**). Eight thermal conductivity samples were collected from this well. Six of the samples lie in the conductive zone and were used to constrain the heat flow determination.

Table 5: *Samples, thermal conductivity values and sub-sections boundaries for well AB36. N/A means that the sample was not used for the heat flow modelling.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122310	54.75	Fine-grained sandstone, hematite banding	3.11	0.19	N/A	N/A
2122311	156.04	Fine-grained grey sandstone	2.96	0.47	N/A	N/A
2122312	253.70	Fine to medium-grained grey sandstone, some < 20 mm lithic clasts	4.28	0.35	165 - 278	Gamma and gradient logs
2122313	351.20	Fine-grained sandstone, hematite staining, quartz veining	5.24	1.16	278 – 418	Gamma and gradient logs
2122314	448.30	Pebbly quartz sandstone	4.95	0.06	418 – 478	Gamma and gradient logs
2122315	645.50	Grey siltstone	5.04	0.08	478 – 697	Gamma and gradient logs
2122490	744.10	Siltstone	4.93	0.03	697 – 760	Gamma and gradient logs
2122317	789.60	Dark siltstone	3.07	0.35	760 – 791	Gamma and gradient logs

The modelled temperature data is plotted along with the measured temperature log in **Figure 7**. There is a good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries. It is expected that the error would be reduced if lithology information was available to constrain the sub-section boundaries and if more thermal conductivity samples were available. Determination of the true depth would be improved with access to well deviation survey data.

There is good agreement with AB56 (described below) that was logged at the same time as this well. It is notable that the heat flow determinations for both these wells are among the highest observed in the western third of the continent. The determinations presented here have been performed as rigorously as possible with the available data but further exploration work including more regional heat flow determinations, is required before it can be assumed that these elevated values are characteristic of the region.

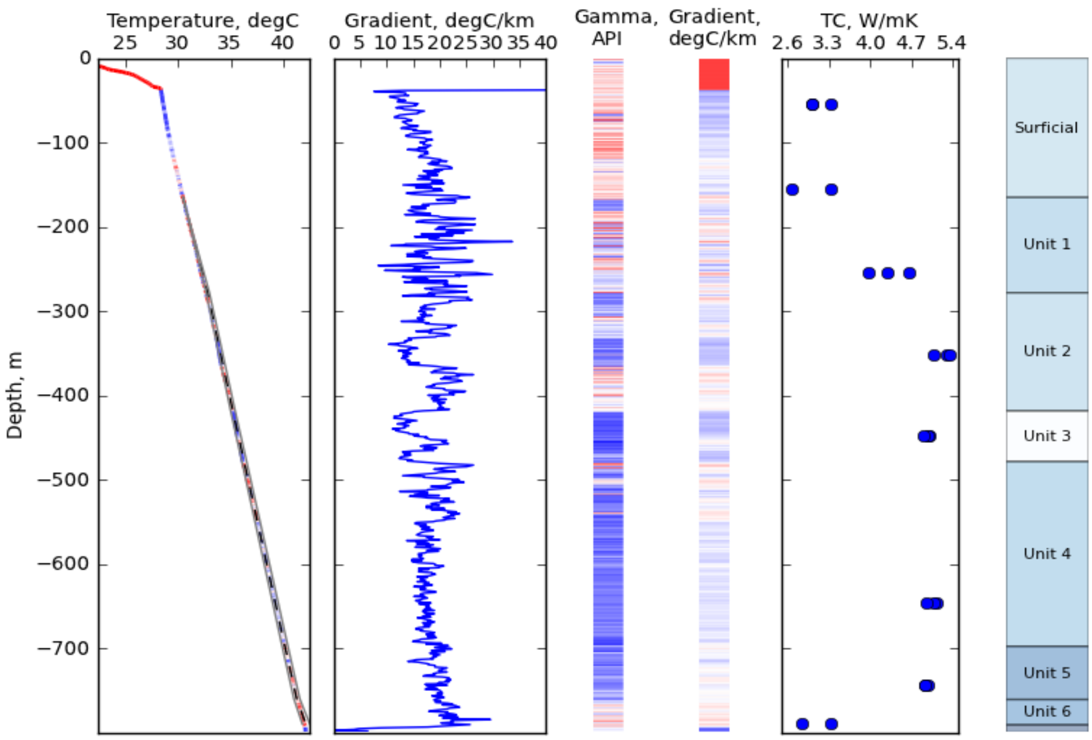

Figure 6: *Temperature log of well AB36 with the calculated gradient. The gamma log is also displayed using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

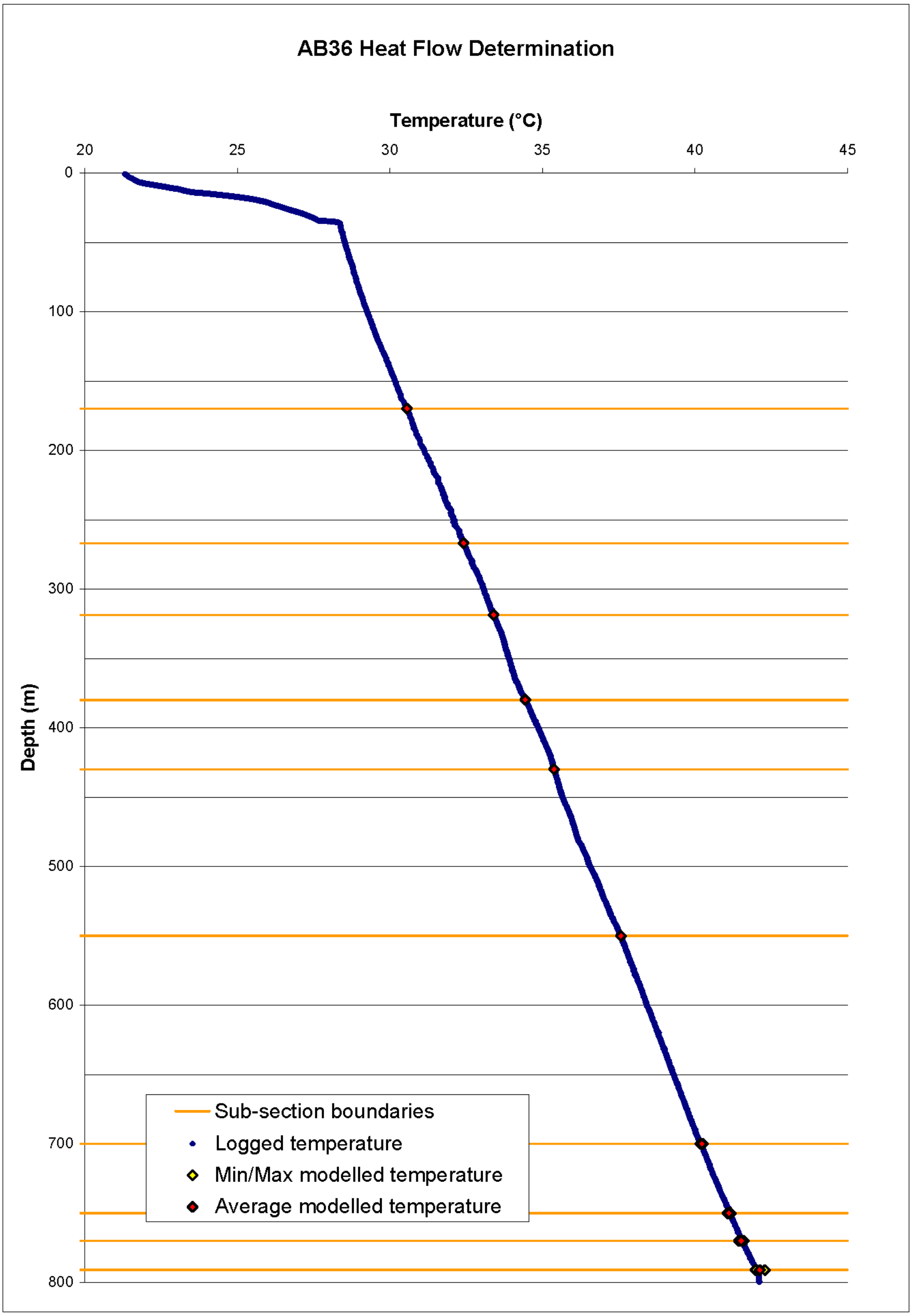

Figure 7: *Modelled and measured temperatures versus true vertical depth for AB36. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

AB56

AB56 is located in the Mesoproterozoic Edmund Basin, approximately 200 km north of Meekatharra in Western Australia. The area is generally flat with sparse scrub and small trees. The well was drilled by Abra Mining Limited and logged by GA using the combined temperature/gamma probe (Auslog A626) to an estimated true vertical depth of 695 m. AB56 is 472 m north-northwest of AB36.

The temperature profile is shown in **Figure 8** and from this the conductive zone has been defined between 220 m to 692 m depth. Above this zone the thermal conditions are likely to be disturbed by surface effects as it was not possible to fit the data (see **Figure 9**).

A heat flow of $86 \pm 3\ mW/m^2$ has been determined for this well. Where possible the gamma log was used to constrain sub-section boundaries, otherwise boundaries were assigned as the midpoint between two thermal conductivity samples (Table 6). Four thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain the heat flow determination.

Only a limited number of samples were collected for this well and there was a large section of the core that was avoided, due to visible mineralisation. As a consequence there is a gap in the depths from which samples were taken. This caused difficulty when trying to model the heat flow. Upon inspection of the gamma logs from AB36 and AB56, it was noticed that there is an obvious correlation between the two. This was then used to apply the thermal conductivities measured for samples from AB36 to those sub-sections of AB56 that did not have thermal conductivity measurements. These sub-sections have been marked with an asterisk in Table 6 and are shown by red markers in **Figure 8**. This process would have been more robust had lithology logs been available, however the good agreement between the gamma logs from the two wells and the fact that only 472 m separates the two wells provides a sound basis for this assumption.

Table 6*: Samples, thermal conductivity values and sub-sections boundaries for well AB56. N/A means that the sample was not used for the heat flow modelling. An asterisk denotes thermal conductivity measurement of sample from well AB36.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122309	54.08	Coarse-grained sandstone	4.46	0.21	N/A	N/A
2122305	138.17	Fine to medium grained, dark grey sandstone	4.86	0.09	N/A	N/A
2122306	231.18	Fine-grained grey sandstone	3.83	0.32	220-312	Gamma and gradient logs
2122307	313.62	Fine to medium grained grey sandstone	5.06	0.07	312-335	Gamma and gradient logs
2122314*	AB36*	Pebbly quartz sandstone*	4.95*	0.06*	335-428*	Gamma and gradient logs*
2122315*	AB36*	Grey siltstone*	5.04*	0.08*	428-574*	Gamma and gradient logs*
2122490*	AB36*	Siltstone*	4.94*	0.03*	574-645*	Gamma and gradient logs*
2122308	689.78	Very fine to fine-grained grey sandstone	4.50	0.35	645-692	Gamma and gradient logs

The modelled temperature data is plotted along with the measured temperature log in **Figure 9**. There is good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries. It is expected that the error would be reduced if lithology information was available to constrain the sub-section boundaries and if more thermal conductivity samples were available. Determination of the true depth would be improved with access to well deviation survey data.

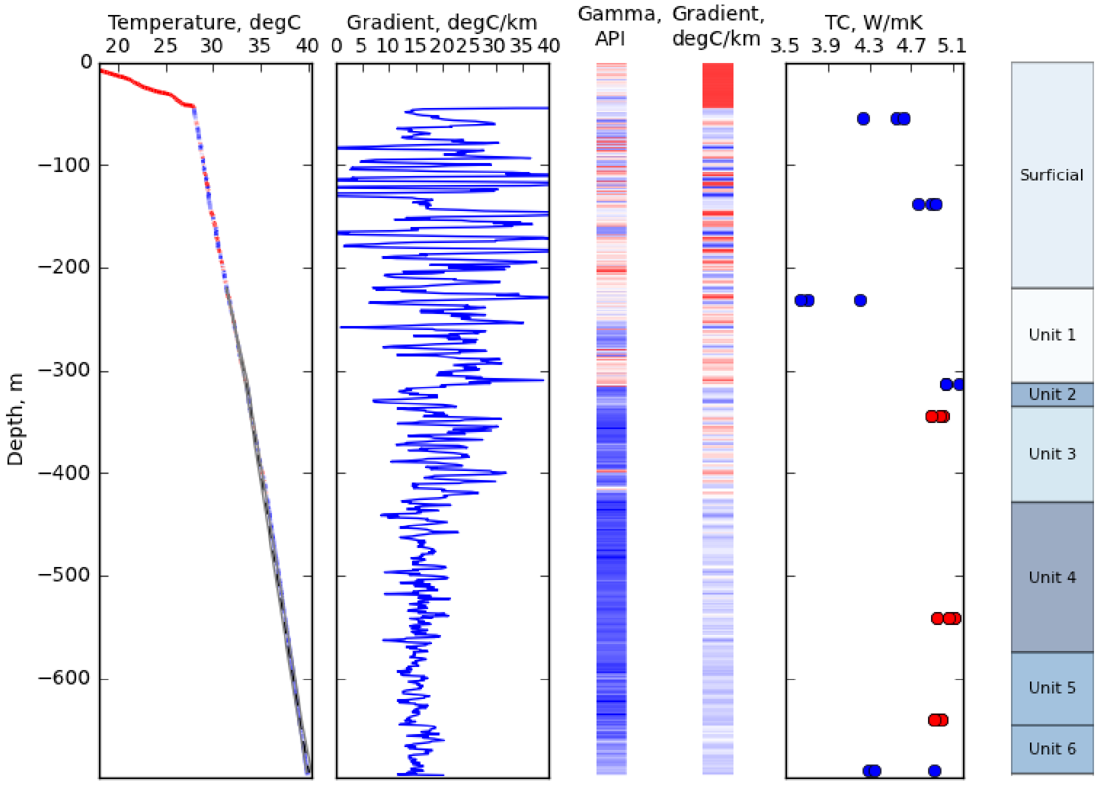

Figure 8: *Temperature log of well AB56 and the calculated gradient. The gamma log is also displayed using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples, the red markers represent sections defined using thermal conductivities from well AB36. On the far right is a representation of the geological model on which the heat flow determination is based.*

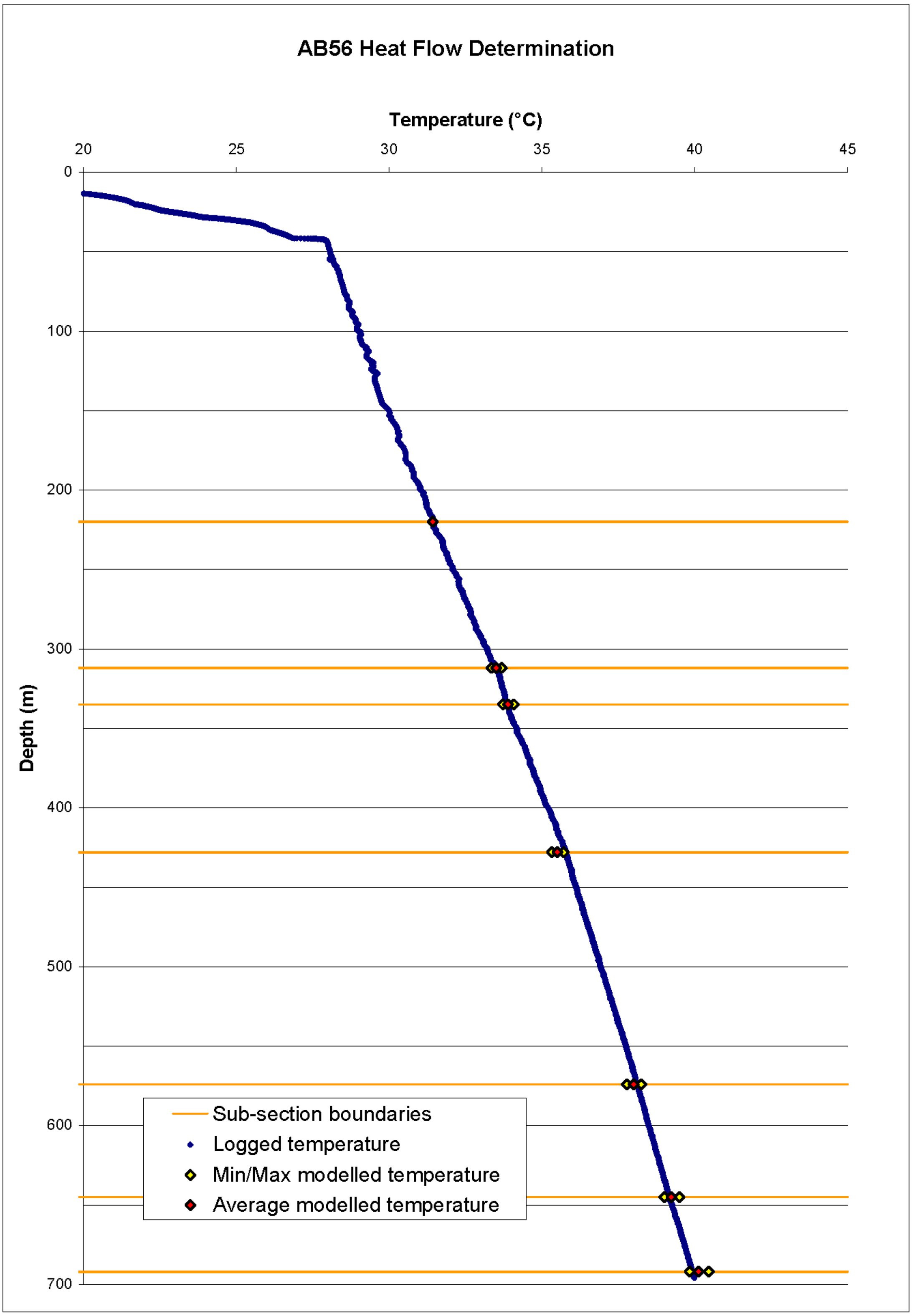

Figure 9: *Modelled and measured temperatures versus true vertical depth for AB56. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

Note on AB36 and AB56

There is good agreement between AB36 and AB56, which were both logged during the same visit to the Abra site. It is notable that the heat flow determinations for these wells are among the highest observed in the western third of the Australian continent. The proximity of the Abra Cu-Pb-Ba mineralisation may be a contributing factor. Abra is a Proterozoic aged, strata-bound hydrothermal deposit that has been linked to the tectonic evolution of the Edmund and Collier basins. Vogt and Stumpfl (1987) propose a model involving the mobilisation of metal-bearing fluids from the basal Bangemall Super Group driven by an elevated heat flow. Rasmussen et al. (2010) provide evidence for a number of hydrothermal events ranging in age from c. 1675 Ma to c. 1030 Ma, indicating a long history of thermal activity. That is not to say that it is expected that the area is still in thermal disequilibrium but rather that the effects of the historical thermal conditions (i.e. the emplacement of the mineralisation), may be associated with the unexpectedly high heat flows. Additionally, structural features associated with the deposit such as faults may be providing current day conduits for increased movement of heat through the system.

It is noted that the thermal conductivities for all lithologies measured at this site are relatively high (generally above >4 W/mK). When considered on the continental scale, the overall thermal gradient is unremarkable at about 18.5 °C/km; it is however, about 50% higher than has been observed at other locations in the Yilgarn and Pilbara.

The determinations here have been performed as rigorously as possible with the available data, but further exploration work to collect more data and interpret existing non-thermal data is required before it can be assumed that these elevated values are characteristic of the region.

CMRD063

CMRD063 is located near Inverell in north-eastern New South Wales. The well was drilled by Malachite Resources Limited with a collar orientation of -66°/161° and logged by GA using the combined temperature/gamma probe to a true vertical depth of 369 m. A lithology log and well orientation information were provided to GA.

The temperature profile is shown in **Figure 10** and from this the conductive zone has been defined as 150 m to 359 m. It was not possible to fit the data above this zone, likely due to disturbance of the thermal conditions by surface effects (see **Figure 11**).

A heat flow of $76 \pm 3\ mW/m^2$ has been determined for this well. The lithology log was used to constrain sub-section boundaries in conjunction with the gamma and gradient logs (**Table 7**). Three thermal conductivity samples were collected from this well but only two of them lie in the conductive zone and were used to constrain the heat flow determination.

Table 7: *Samples, thermal conductivity values and sub-sections boundaries for well CMRD063. N/A means that the sample was not used for the heat flow modelling.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115217	87.8	Coarse-grained volcaniclastic	2.92	0.09	N/A	N/A
2115218	213.9	Coarse-grained volcaniclastic	2.81	0.01	149.95 - 215.6	Lith log
2115219	347.3	Coarse-grained pink granite	2.64	0.12	215.6 – 347.3	Lith Log

The modelled temperature data is plotted along with the measured temperature log in **Figure 11**. There is a reasonable agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries. It is expected that the reliability of the heat flow determination could be improved with more thermal conductivity samples to increase the number of sub-sections.

This well is collared approximately 45 m to the south of CMRD076 (see below). Due to the orientation of the two wells, CMRD063 terminates approximately 107 m to the southeast of CMRD0076. The heat flow determinations of the two wells are compared below.

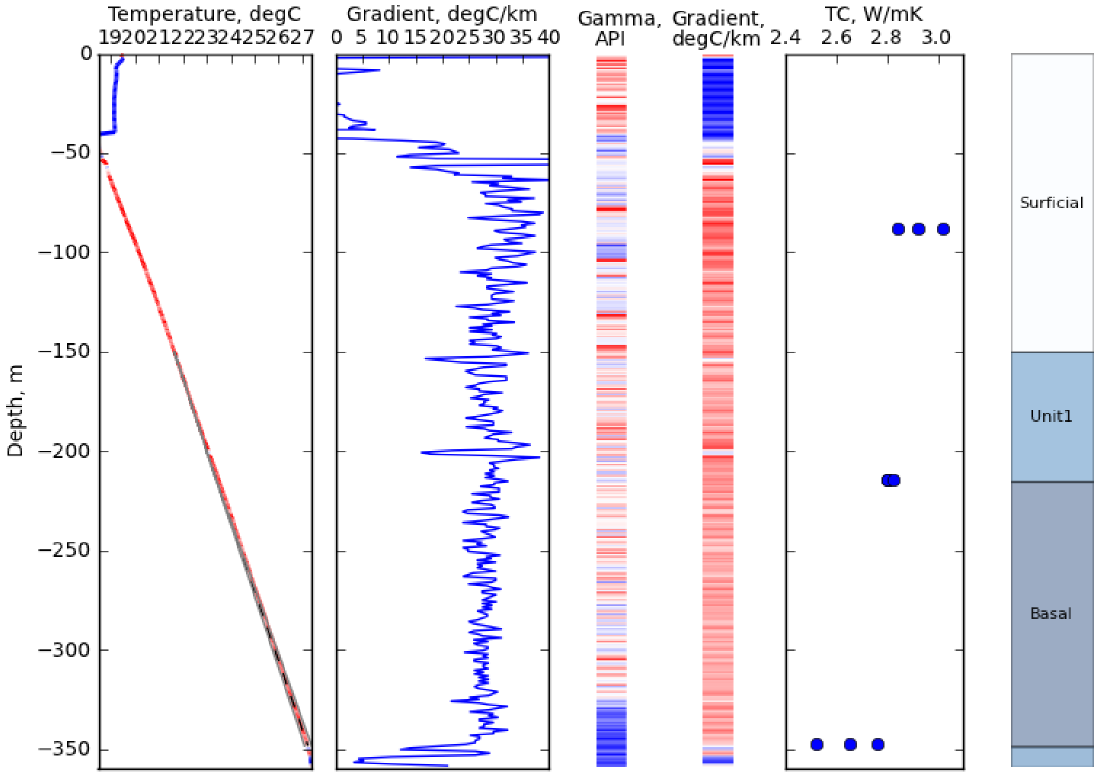

Figure 10: *Temperature log of well CMRD063 with the calculated gradient. The gamma log is also using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

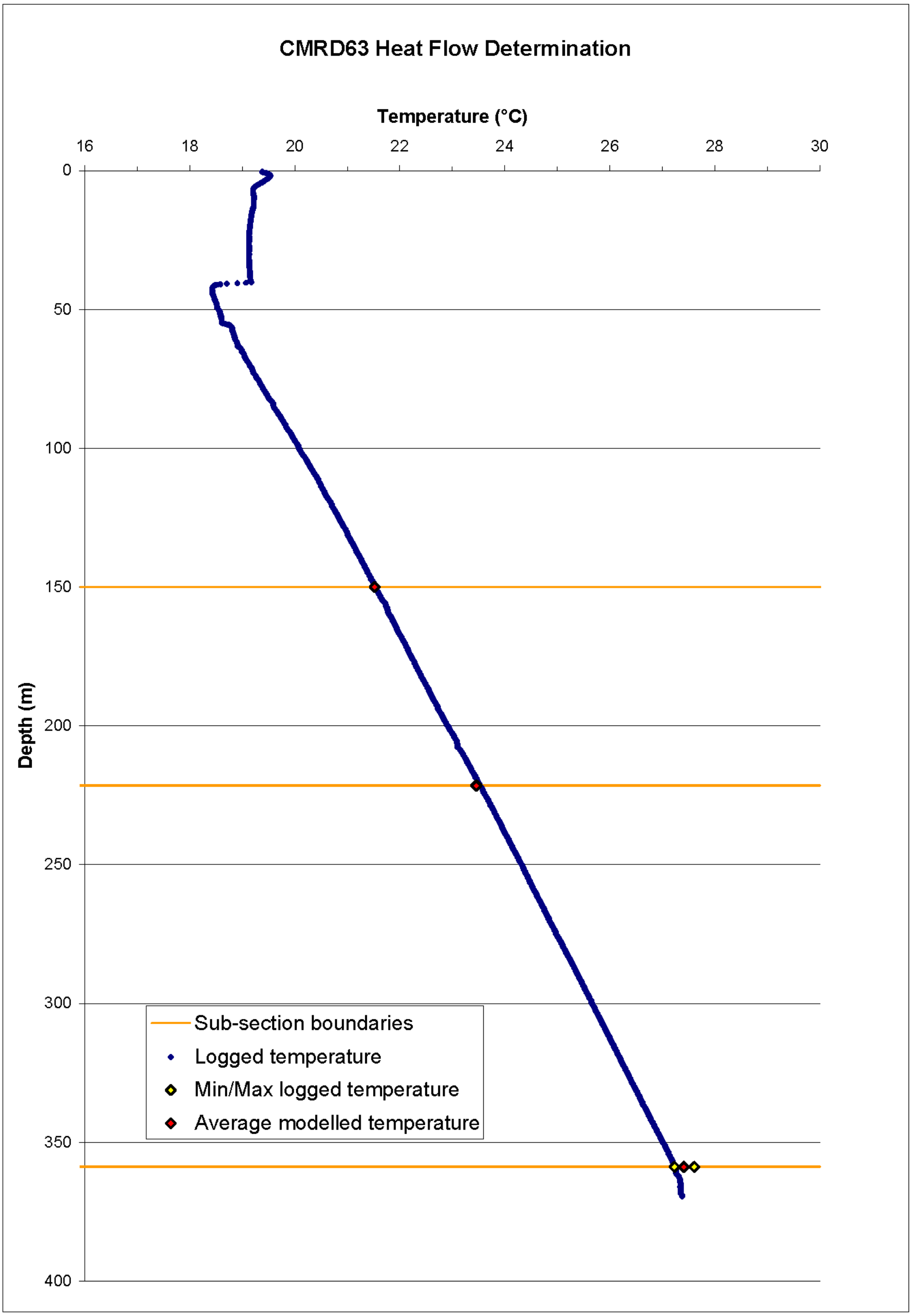

Figure 11: *Modelled and measured temperatures versus true vertical depth for CMRD063. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

CMRD076

CMRD076 is located near Inverell in north-eastern New South Wales. The well was drilled by Malachite Resources Limited with a collar orientation of -73°/198° and logged by GA using the combined temperature/gamma probe to a true vertical depth of 518 m. A lithology log and well orientation information were provided to GA.

The temperature profile is shown in **Figure 12** and from this the conductive zone has been defined as 150 m to 515 m depth. It was not possible to fit the data above this zone, likely due to disturbance of the thermal conditions by surface effects. Although the sample taken from 511 m (true depth) was used in the heat flow modelling, the temperature log at this point appears to be influenced by the proximity of the bottom of the hole (see **Figure 13**).

A heat flow of $78.5 \pm 1.5\ mW/m^2$ has been determined for this well. The supplied lithology log and the recorded gamma and thermal gradient logs were use to define the sub-section boundaries (**Table 8**). Six thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain the heat flow determination.

Table 8: *Samples, thermal conductivity values and sub-sections boundaries for well CMRD076.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115220	153.98	Coarse-grained pink granite	2.84	0.07	150-168	Lithology Log
2115221	210.60	Coarse-grained pink granite	2.91	0.03	168-235	Lithology Log
2115222	270.68	Porphyritic light-grey granite	2.99	0.08	235-280	Lithology Log
2115223	297.77	Coarse-grained pink granite	2.99	0.05	280-385	Lithology Log
2115224	420.70	Coarse-grained pink granite	2.70	0.17	385.440	Lithology log
2115224	511.84	Coarse-grained pink granite	2.78	0.09	440 - 515	Lithology log

The modelled temperature data is plotted along with the measured temperature log in **Figure 13**. There is a good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries. It is expected that the error would be reduced further if a greater number of thermal conductivity samples were available.

There is also reasonable agreement with the other hole in the area (CMRD063), which is collared approximately 45 m to the south (but the two holes terminate about 107 m apart.). The heat flow determinations for the two wells are within error of each other (78.5 ± 1.5 and $76 \pm 3\ mW/m^2$), although it is likely that the value for this well (CMRD076) is more reliable given the greater density of thermal conductivity measurements and thus more robust modelling.

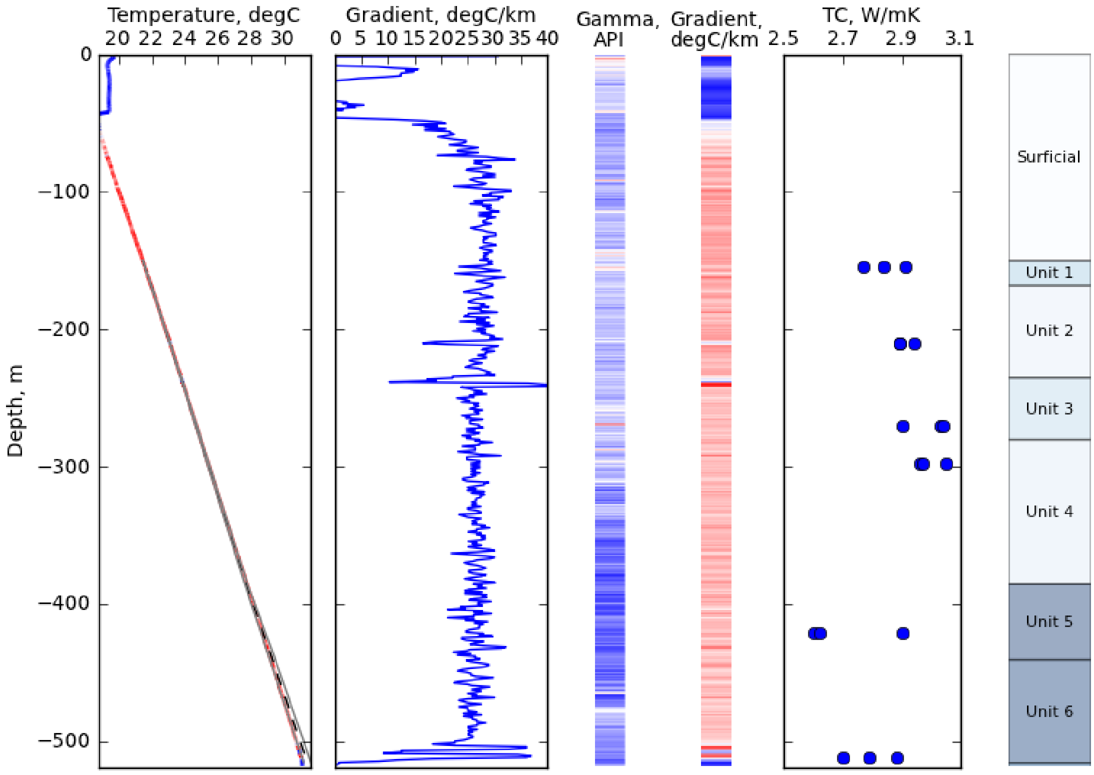

Figure 12: *Temperature log of well CMRD076 with the calculated gradient. The gamma log is also using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

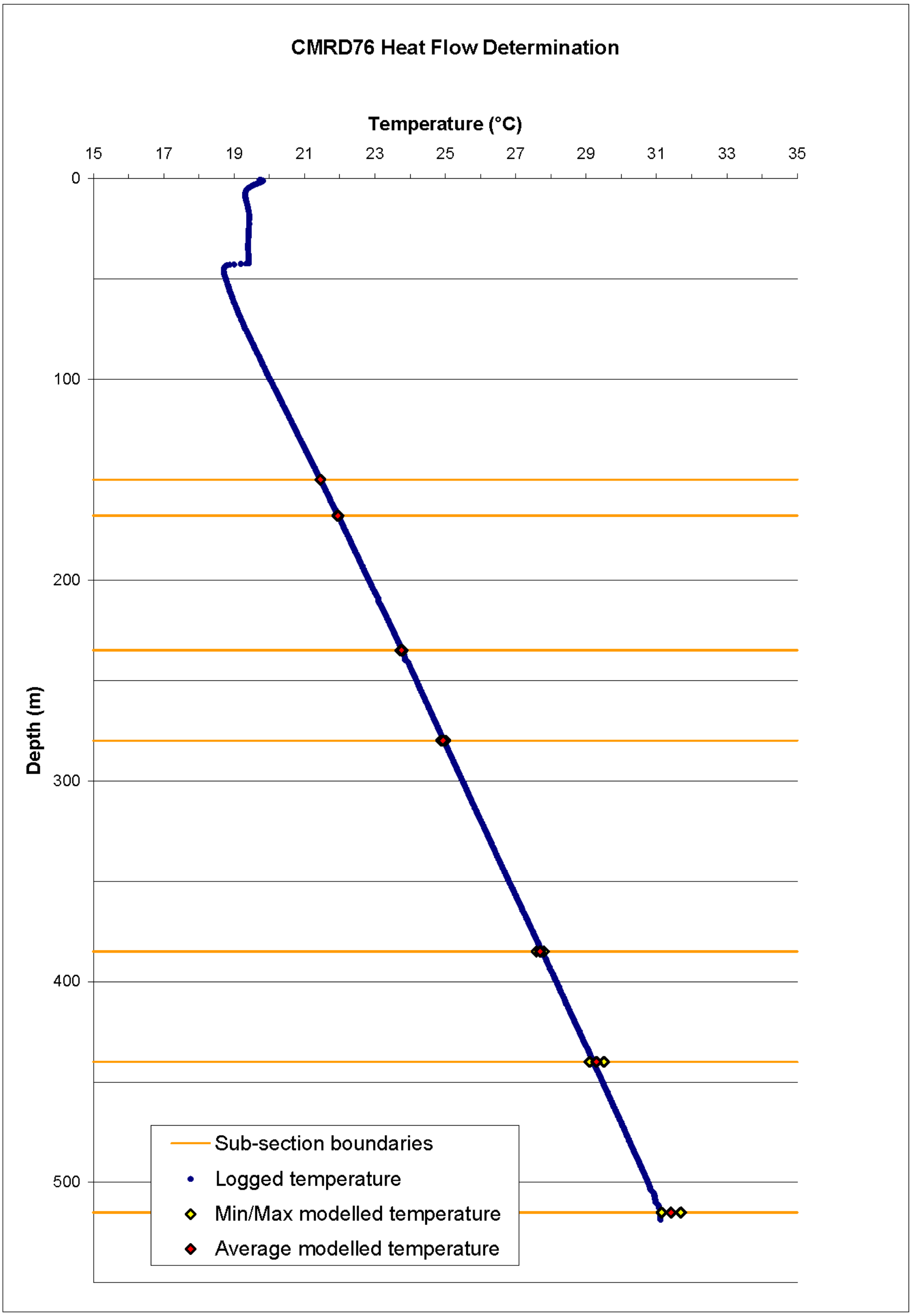

Figure 13: *Modelled and measured temperatures versus true vertical depth for CMRD076. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

CNYDD002

CNYDD002 is located near Nymagee in central New South Wales. The well was drilled by the previous owner of the prospect, Triako Resources at an inclination of -75° and logged by GA using the temperature-only probe (Auslog A621) to a true vertical depth of 635 m. The site is now owned by YTC Resources Limited.

The temperature profile is shown in Figure 14 and from this the conductive zone has been defined between 120 m to 617 m depth. Above this zone the gradient is likely to be disturbed by surface effects (see Figure 15).

A heat flow of $72.5 \pm 3.5\ mW/m^2$ has been determined for this well. Sub-section boundaries were defined using the character of the temperature gradient log (Table 9). Six thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain the heat flow determination. The temperature log itself is quite noisy and disrupted on a small scale. By determining the heat flow over a large section of the log, it has been possible to reduce the influence of this high frequency noise on the calculation.

Table 9: *Samples, thermal conductivity values and sub-sections boundaries for well CNYDD002.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115226	143.7	Slate	3.62	0.03	120-192	Gradient Log
2115227	221.6	Medium grey, fine- grained metasediment	3.71	0.24	192-270	Gradient Log
2115228	302.1	Medium grey, fine- grained metasediment	3.91	0.10	270-330	Gradient Log
2115229	377.7	Medium grey, fine- grained metasediment	4.1	0.28	330-445	Gradient Log
2115230	528.4	Medium grey, fine- grained metasediment	3.72	0.24	445-570	Gradient Log
2115231	602.7	Micaceous metamorphic rock, phyllite?	3.93	0.30	570-617	Gradient Log

The modelled temperatures are plotted with the measured temperature log in Figure 15. There is good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries, although the noisy nature of the log reduces the level of reliability. It is expected that the error would be reduced if lithology and well orientation information were available to constrain the sub-section boundaries and provide a more accurate vertical depth correction.

Two other wells in this report are in the immediate vicinity of this well (CNYDD008 and TNY020). There are also two wells proximal to CNYDD002 for which GA has previously published heat flow determinations: CNYDD004 (Kirkby and Gerner, 2010) and TNY046 (Weber et al., 2011), with heat flows determined to be 93 mW/m^2 and 66.5 mW/m^2 respectively. There is a high degree of variability between these five wells, the cause of which is not immediately apparent. Given the level of noise in the logs it is possible that there may be larger scale thermal disturbances in the area that are not visible in the individual logs. These disturbances may be due to the proximity of mineralisation or associated structural features such as faulting. They may also be caused by the movement of fluid through the system, although this is not apparent in these logs.

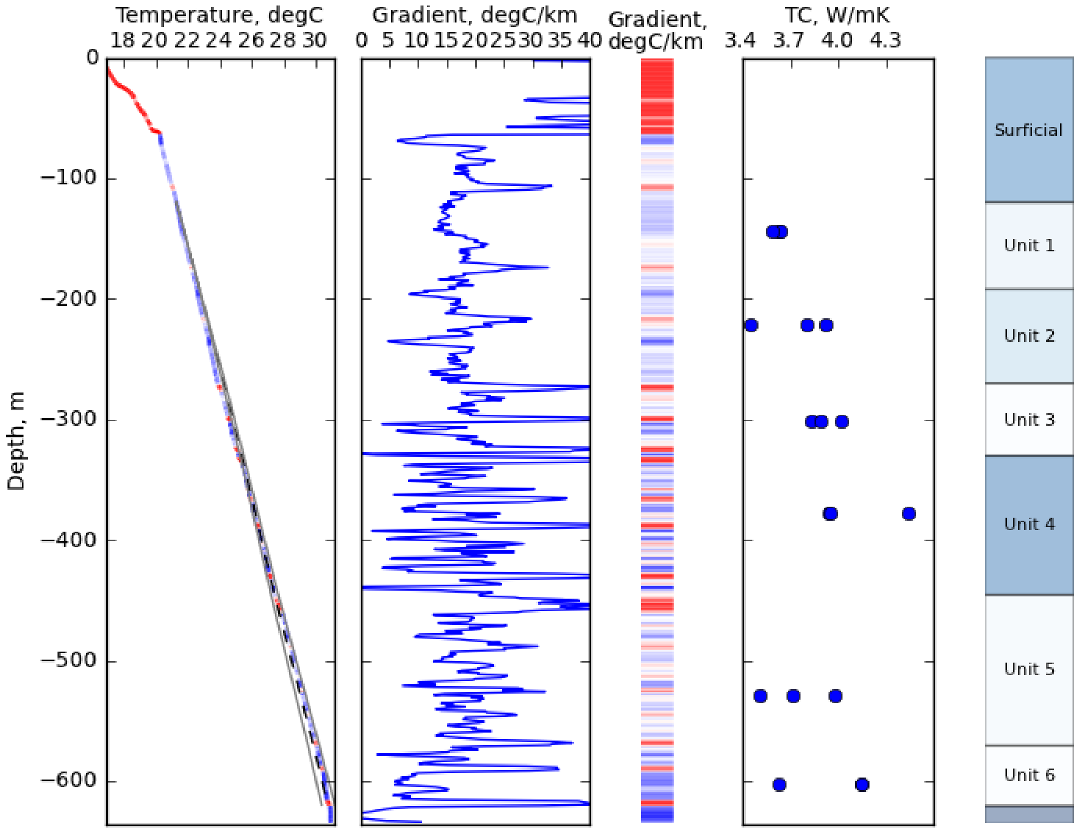

Figure 14: *Temperature log of well CNYDD002 with the calculated gradient. Another representation of the calculated gradient is also displayed using a variable colour scale (blue (low) to red (high)) alongside. This scale is purely relative and has been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

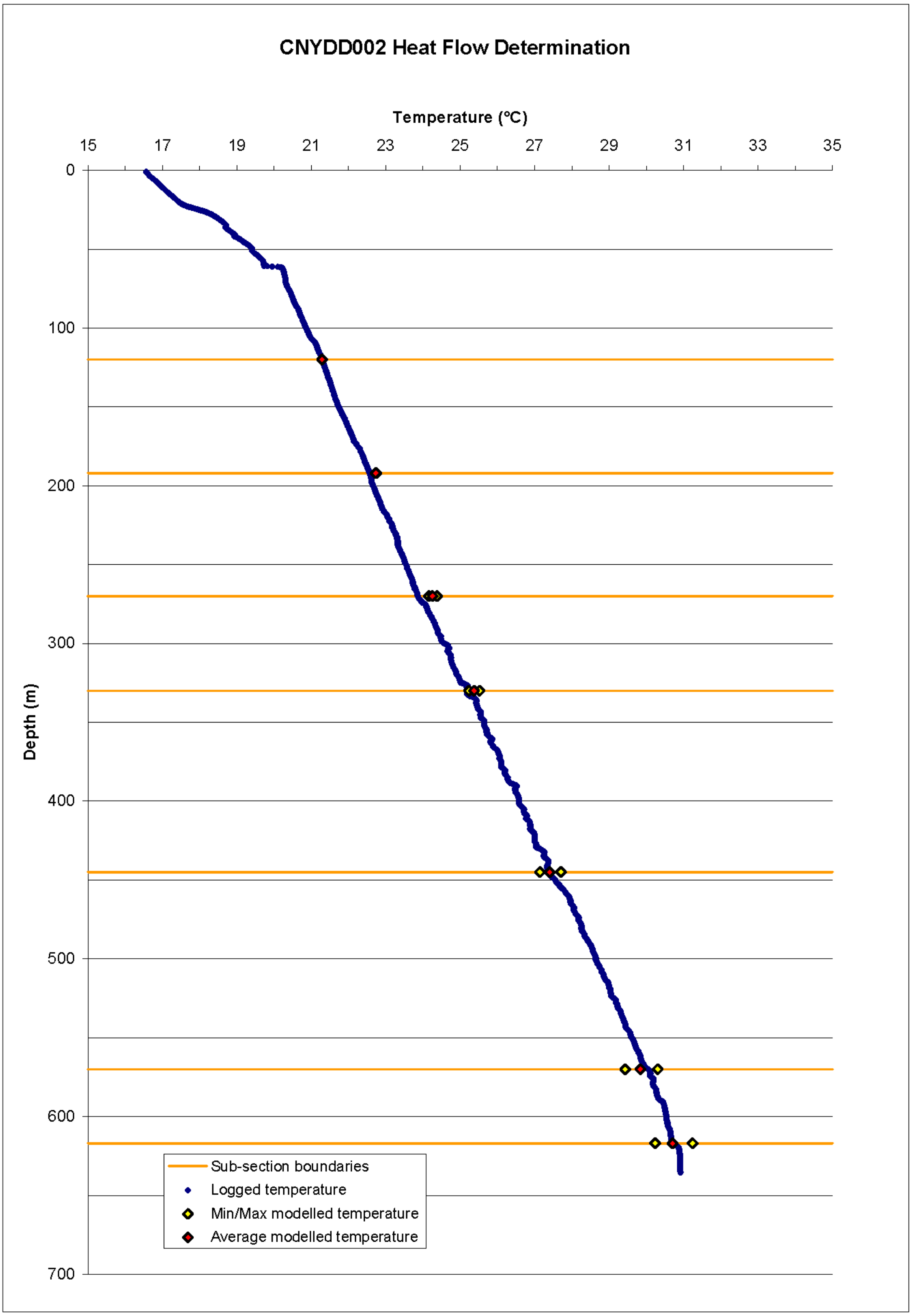

Figure 15: *Modelled and measured temperatures versus true vertical depth for CNYDD002. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

CNYDD008

CNYDD008 is located near Nymagee in central New South Wales. The well was drilled by the previous owner of the prospect, Triako Resources at an inclination of -65°and logged by GA using the temperature-only probe (Auslog A621) to a true vertical depth of 596 m. The site is now owned by YTC Resources Limited.

The temperature profile is shown in Figure 16 and from this the conductive zone has been defined between 145 m to 580 m depth. Above this zone the gradient is disturbed by surface effects (see Figure 17). The temperature log itself is quite noisy and disrupted on a small scale. It has been possible to reduce the influence of this high frequency noise on the calculation by determining the heat flow over a large section of the log.

A heat flow of $51 \pm 3\ mW/m^2$ has been determined for this well. Sub-section boundaries were defined using the character of gradient log (Table 10). Six thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain the heat flow determination.

Table 10: *Samples, thermal conductivity values and sub-sections boundaries for well CNYDD008.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115241	145.4	Micaceous, fine-grained metasediment, undulating foliation, phyllite?	3.31	0.02	145-167	Gradient Log
2115242	208.6	Fine-grained metasediment, undulating foliation, contains pyrite and chalcopyrite	3.02	0.13	167-218	Gradient Log
2115243	280.9	Fine-grained metasediment, undulating foliation	2.81	0.61	218-282	Gradient Log
2115244	418.7	Fine-grained metasediment, undulating foliation	2.97	0.05	282-424	Gradient Log
2115245	498.5	Fine-grained metasediment, undulating foliation	3.04	0.06	424-560	Gradient Log
2115246	570.8	Grey fine-grained metasediment with quartz/calcite on cleavage planes	2.85	0.21	560-580	Gradient Log

The modelled temperatures are plotted along with the measured temperature log in Figure 17. There is good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigned sub-section boundaries. It is expected that the error would be reduced if lithology information was available to constrain the sub-section boundaries.

As mentioned earlier in this report (refer to well CNYDD002), there are 5 wells that GA has logged in the Nymagee area: the heat flow determinations are variable ranging between 51 and 93 mW/m^2. The cause of this variability is presently unknown.

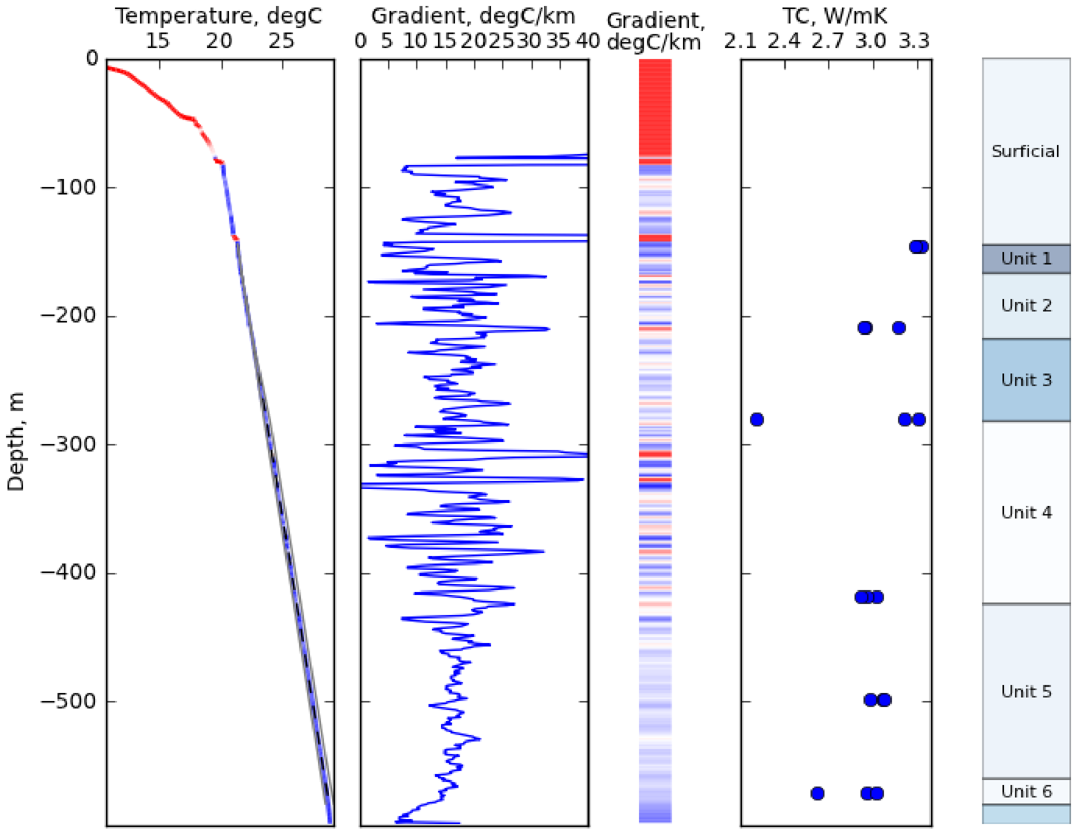

Figure 16: *Temperature log of well CNYDD008 with the calculated gradient. Another representation of the calculated gradient is also displayed using a variable colour scale (blue (low) to red (high)) alongside. This scale is purely relative and has been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

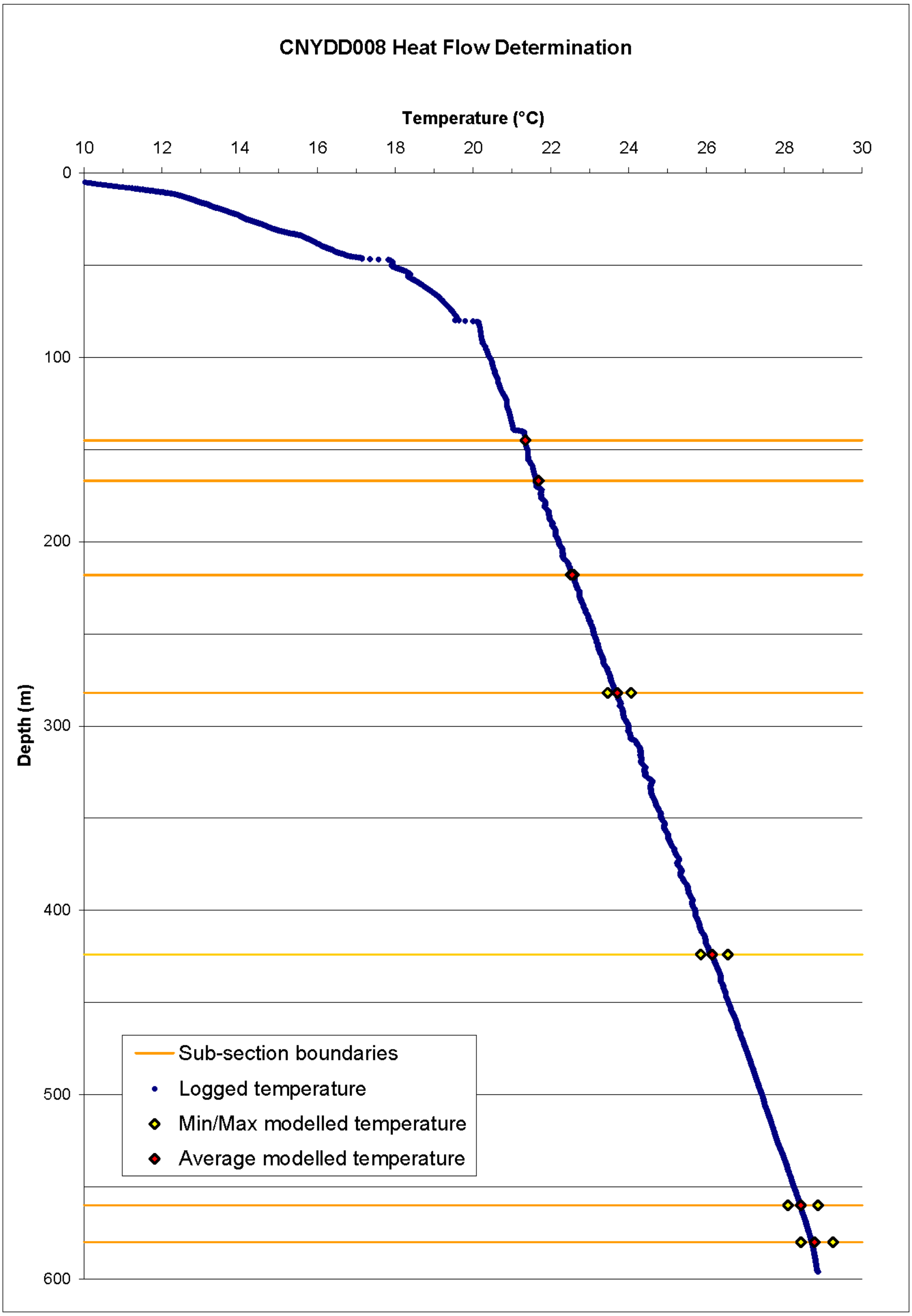

Figure 17: *Modelled and measured temperatures versus true vertical depth for CNYDD008. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

FFD195

FFD195 is located near Forrestania, Western Australia. The well was drilled by Western Areas NL at an orientation of -72°/270° to a total depth of 1513 m. Due to a blockage in the well it was logged by GA to a depth of 801.4 m using the combined temperature/gamma probe. This is equivalent to a vertical depth of 753 m. A lithology log was provided to GA. All depths mentioned below have been corrected to true vertical depth.

The temperature profile is shown in **Figure 18** and from this the conductive zone has been defined between 136.8 m to 741.8 m depth. Above this zone the gradient is disturbed and below this zone the regime is no longer purely conductive. This can be best observed in a calculated gradient log but can also be seen at a very small scale in the temperature log (see **Figure 19**).

A heat flow of $34.5 \pm 4\ mW/m^2$ has been determined for this well. The boundaries were constrained predominantly using the lithology log and refined by cross-referencing with the thermal gradient and the gamma log. The data were detailed enough that it was possible to apply the measured thermal conductivities from one depth to sections of similar lithology at other depths in the well. These are shown in red in Figure 18. Eight thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain ten sub-sections for the heat flow determination (**Table 11**).

Table 11: *Samples, thermal conductivity values and sub-sections boundaries for well FFD195.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122069	149.3	Basalt, veins at 45 degrees to core direction	2.64	0.15	137-248	Lith log with gamma and gradient
2122070	262.1	Pelite	3.02	0.65	248-302	Lith log with gamma and gradient
2122071	309.9	Pelite, pyrite and chalcopyrite mineralisation	2.64	0.15	302-318	Lith log with gamma and gradient
2122072	338.4	Dolerite, coarse-grained	3.02	0.65	318-464	Lith log with gamma and gradient
2122073	428.2	Pelitic meta-sedimentary rock	1.69	0.13	464-472	Lith log with gamma and gradient
2122074	500.3	Pelitic meta-sedimentary rock	2.09	0.35	472-553	Lith log with gamma and gradient
2122075	569.3	Pelite	2.73	0.26	553-608	Lith log with gamma and gradient
2122076	621.0	Pelite	3.89	0.2	608-654	Lith log with gamma and gradient

The modelled temperatures are plotted along with the measured temperature log in **Figure 19**. There is good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of assigning a thermal conductivity measured from a limited size sample to a large sub-section of the log. It is expected that the error would be reduced if there were a greater number of samples with thermal conductivity measurements available and if a well orientation survey were available.

There are two heat flow determinations in the immediate area of this well and they are in moderate agreement with this determination. The closest (NMD134) is approximately 4 km to the south south-west and has a value of 44 mW/m^2. The second (SED246) is 34 km to the south south-east and has a value of 34 mW/m^2 (Kirkby and Gerner, 2010).

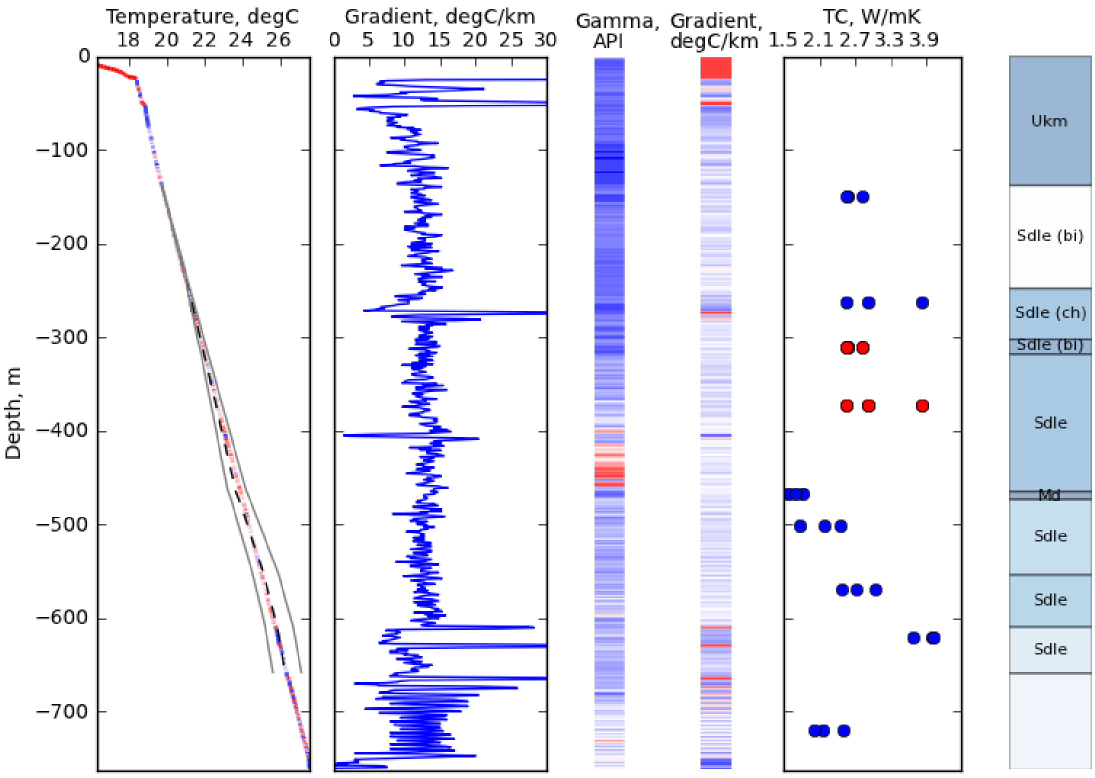

Figure 18: *Temperature log of well FFD195 with the calculated gradient. The gamma log is also using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples, the red markers represent sections defined using thermal conductivities from elsewhere in well. On the far right is a representation of the geological model on which the heat flow determination is based.*

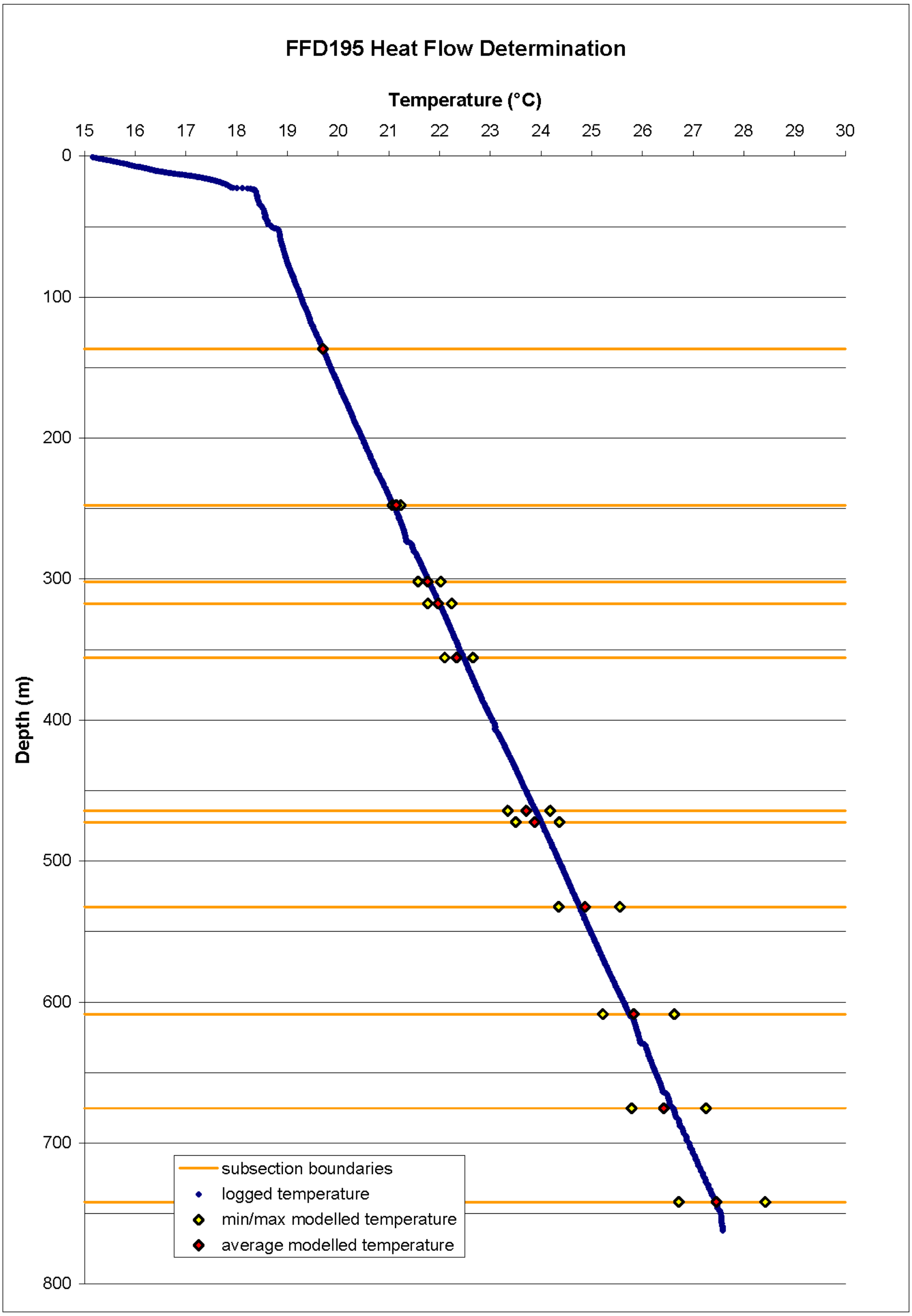

Figure 19: *Modelled and measured temperatures versus true vertical depth for FFD195. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

SPDD0014

SPDD0014 is located in the Tanami province in Western Australia. The well was drilled by Tanami Gold NL at an orientation of -60° to a total depth of 349 m. It was logged by GA using the combined temperature/gamma probe to a depth of 349 m. This is equivalent to a true vertical depth of 301 m. A lithology log and well orientation data were provided to GA. All depths mentioned below have been corrected to true vertical depth.

The temperature profile is shown in **Figure 20**. The depth range across which the samples for thermal conductivity measurements were collected is very small, but within the purely-conductive portion of the log. Five samples were collected between 268 m and 275 m (Table 12). This has provided a detailed analysis of the thermal conductivity for that section of log, which has allowed a precise calculation of heat flow at this point in the well, but we were unable to model the heat flow for the entire log (see **Figure 21**).

A heat flow of *43 ± 2 mW/m*^{2} has been determined for this section of the well. Due to the very short interval over which the thermal conductivity was available, the heat flow was calculated both in a 1D modelling fashion as described in Heat Flow Calculation Method above, and also as a single point by multiplying the harmonic mean of the thermal conductivity values by the average gradient across the section (Beardsmore and Cull, 2001). Both techniques produced values within 0.5 mW/m^2 of each other.

Table 12: *Samples, thermal conductivity values and sub-sections boundaries for well SPDD0014.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2122300	268.0	Dolerite, minor chlorite alteration	3.05	0.06	266.9-269.1	Mid-point
2122301	270.2	Dolerite, minor chlorite alteration	2.72	0.36	269.1-271.0	Mid-point
2122302	271.7	Dolerite, quartz vein	2.35	0.06	271.0-272.7	Mid-point
2122303	273.6	Dolerite, minor pyrite	2.54	0.06	272.7-274.3	Mid-point
2122304	275.0	Dolerite, minor pyrite	2.73	0.01	274.3-275.7	Mid-point

The modelled temperature data is plotted along with the measured temperature log in **Figure 21**. There is good agreement between the measured and modelled data, however this is to be expected over such a small depth interval. The error in the heat flow determination is primarily due to the uncertainty in assigning a thermal conductivity measured from a limited size sample to a large sub-section of the log. While the error on the heat flow determination is relatively low, it is expected that the reliability of the heat flow determination could have been improved if samples for thermal conductivity measurements had been collected from a broader range of depths.

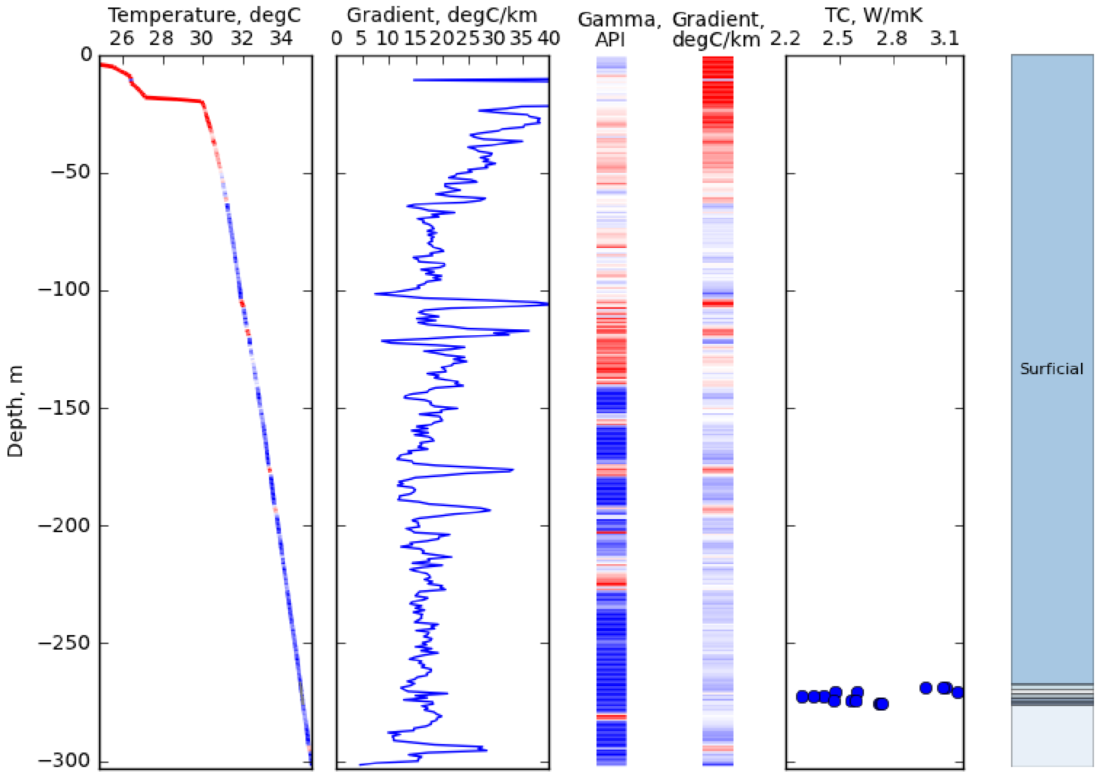

Figure 20: *Temperature log of well SPDD0014 with the calculated gradient. The gamma log is also using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

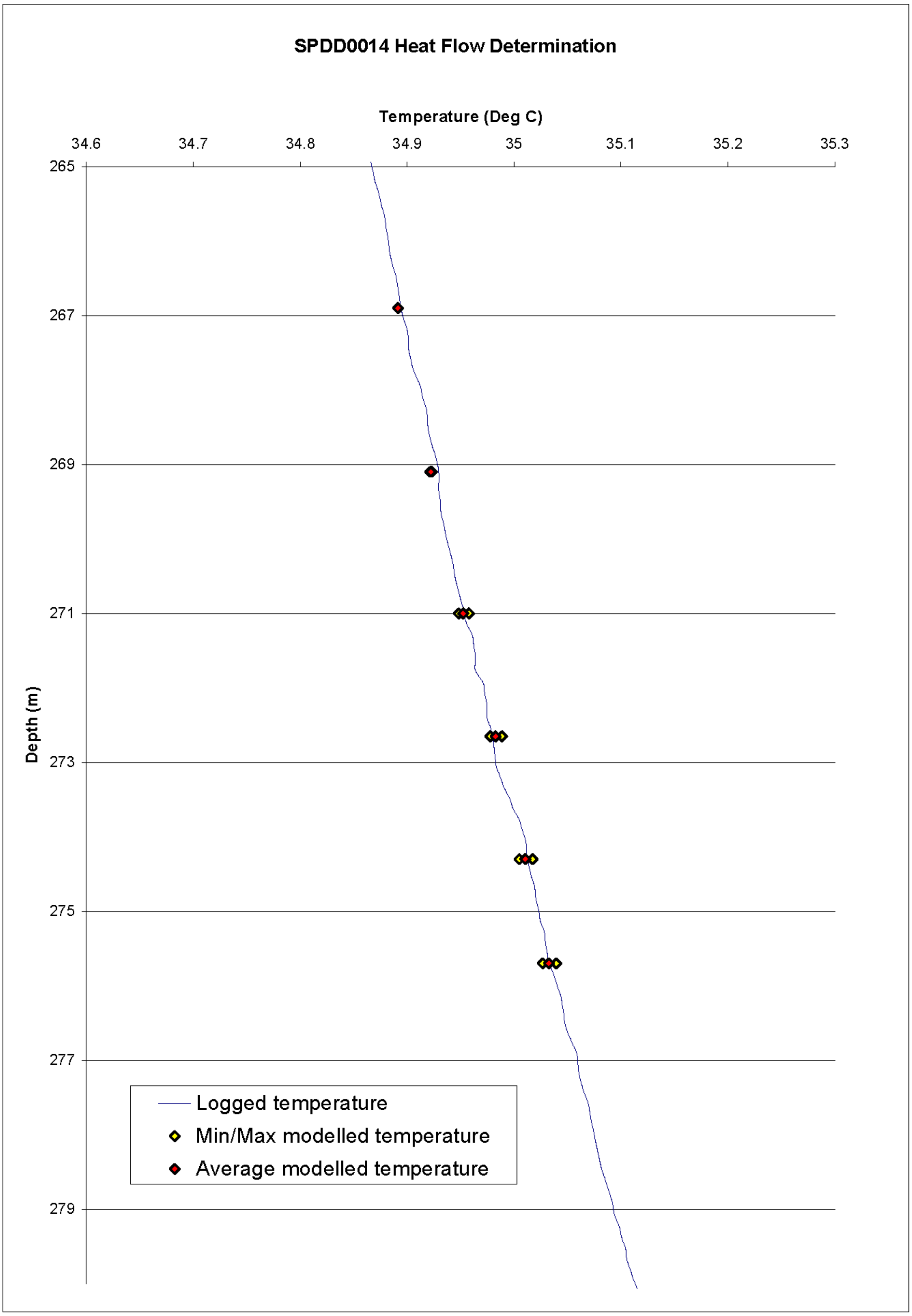

Figure 21: *Modelled and measured temperatures versus true vertical depth for SPDD0014. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

TNY020

TNY020 is located near Nymagee in central New South Wales. The well was drilled by the previous owner of the prospect, Triako Resources at an inclination of -68° to a total depth of 582.3 m. The site is now owned by YTC Resources Limited. The hole was logged by GA using the temperature-only probe (Auslog A621) to a depth of 578 m. This is equivalent to a true vertical depth of 536 m. All depths mentioned below have been corrected to true vertical depth.

The temperature profile is shown in Figure 22 and from this the conductive zone has been defined as 130 m to 460 m depth (Figure 22). Above this zone the gradient is influenced by surface effects and below this zone the gradient is influenced by end-of-hole effects. This can be best observed in a calculated gradient log but can also be seen at a very small scale in the temperature log (see Figure 23). Six samples were collected for thermal conductivity measurement but only five of these were used as the sixth was below the depth of the log.

A heat flow of *53 ± 2.5 mW/m*^{2} has been determined for this well. The sub-section boundaries where defined using the character of the gradient log. Five thermal conductivity samples collected from this well lie in the conductive zone and were used to constrain the heat flow determination.

Table 13: *Samples, thermal conductivity values and sub-sections boundaries for well TNY020. N/A means that the sample was not used for the heat flow modelling.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115247	132.6	Fine-grained metasediment	3.22	0.18	130-183	Gradient Log
2115248	216.0	Phyllite	3.53	0.10	183-230	Gradient Log
2115249	289.7	Fine-grained metasediment, undulating foliation.	3.25	0.12	230-315	Gradient Log
2115250	362.5	Fine-grained metasediment, undulating foliation.	3.25	0.26	315-378	Gradient Log
2115251	445.2	Phyllite	2.89	0.02	378-460	Gradient Log
2115252	536.7	Fine-grained metasediment, undulating foliation, phyllite?	2.61	0.06	N/A	N/A

The modelled temperatures are plotted along with the measured temperature log in Figure 23. There is good agreement between the measured and modelled data. The error in the heat flow determination is primarily due to the uncertainty of the assigning a thermal conductivity measured from a limited size sample to a large sub-section of the log. It is expected that the error would be reduced if a lithology log had been available and if there were a greater number of samples with thermal conductivity measurements.

This heat flow determination for TNY020 is one of three determinations made in the Nymagee area that are presented in this report: refer to wells CNYDD002 and CNYDD008.

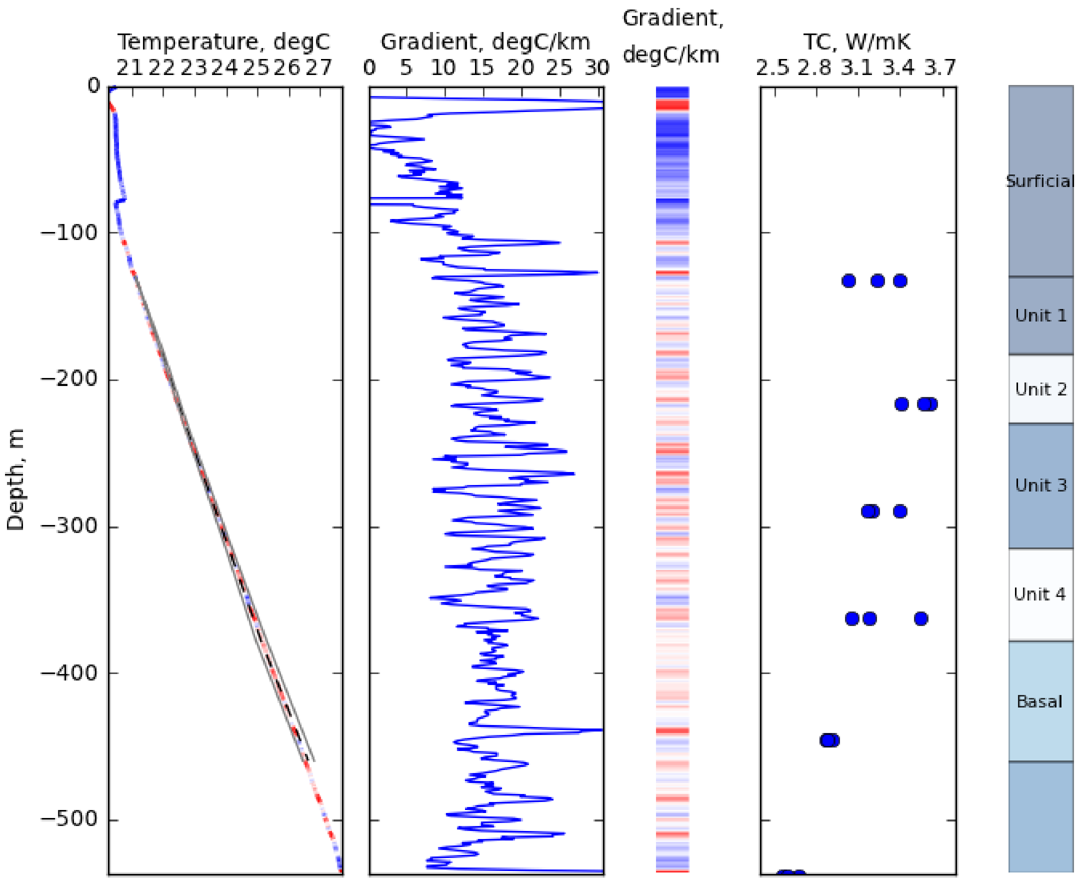

Figure 22: *Temperature log of well TNY020 with the calculated gradient. Another representation of the calculated gradient is also displayed using a variable colour scale (blue (low) to red (high)) alongside. This scale is purely relative and has been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

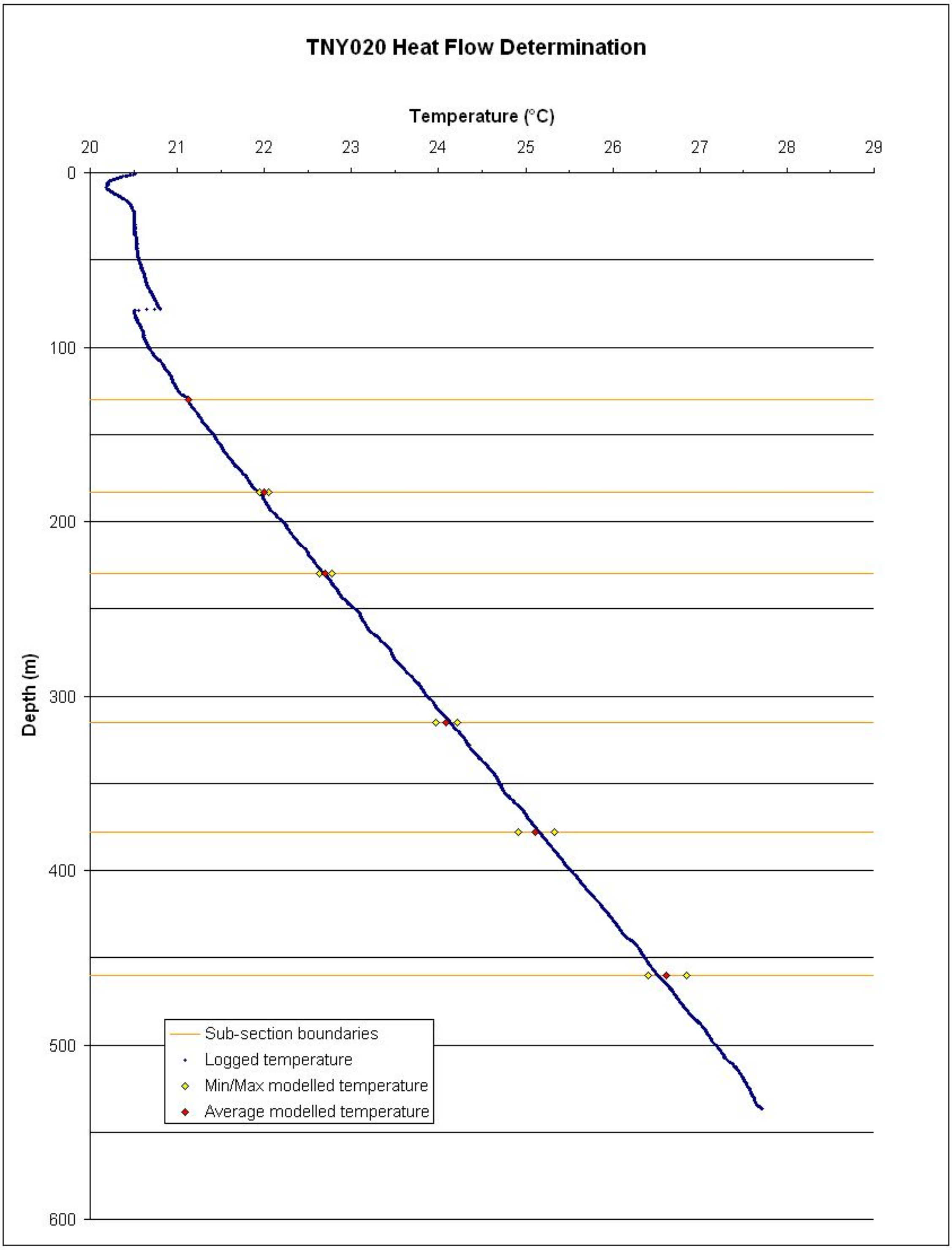

Figure 23: *Modelled and measured temperatures versus true vertical depth for TNY020. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

TTDD005

TTDD005 is located approximately half way between Cobar and Nyngan in western New South Wales. The well was drilled by Tritton Resources at an orientation of -85°/254° to a total depth of 1300 m. It was logged by GA to a depth of 1208 m using the combined temperature/gamma probe. This is equivalent to a true vertical depth of 1195 m. All depths mentioned below are corrected to true vertical depth.

The temperature profile is shown in **Figure 24** and from this the conductive zone has been defined between 677 m to 1173 m depth. Above this zone the gradient was found to be disturbed and it was not possible to model the heat flow with the top section of the well, with the corresponding thermal conductivity measurements, included. This may suggest that the samples from this section of the well are not representative of the lithologies present or that there are other influences on the thermal conditions in the upper part of the well. The thermal conductivities of the samples from the upper section of the well are generally higher than those in the lower section. There also is a noticeable step in the gradient log at about 680 m, which corresponds to a change in the gamma profile across a section between approximately 550 m and 680 m (**Figure 24**). It is possible that this zone is contributing a small amount of heat to the system. It was noted that when only the top section of the well was used in the heat flow modelling, a value slightly higher then the final determination was established. However even using a higher heat flow, a poor fit was achieved for the upper section of the well, suggesting additional thermal disturbance in this section of the well.

A heat flow of $52 \pm 9\ mW/m^2$ has been determined for this well. The boundaries were constrained using the thermal gradient and the gamma log (**Table 14**). Thirteen thermal conductivity samples were collected at the time of logging. Of these six lie in the conductive zone and were used to produce the heat flow determination.

Table 14: *Samples, thermal conductivity values and sub-sections boundaries for well TTDD005. N/A means that the sample was not used for the heat flow modelling.*

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115261	109.8	Some schistosity, some veining, iron staining, fine grain meta-sediments with some coarser small pebbly bands	3.39	0.17	N/A	N/A
2115262	155.1	Slaty, pyrite banded, quartz veins,	1.81	1.09	N/A	N/A
2115263	212.4	Grey, banded, schist,	3.00	0.34	N/A	N/A
2115264	286.6	Coarse-grained, silicified sandstone, some pyrite	4.04	0.35	N/A	N/A
2115265	389.0	Grey schist, quartz veining, originally claystone?	2.3	0.29	N/A	N/A
2115266	487.0	Grey, medium-grained, meta-sediment, minor calcite veining, minor sulphides	4.41	0.26	N/A	N/A
2115267	605.3	Grey meta-sediment, silicified, major quartz veining, some pyrite	5.10	0.47	N/A	N/A

Sample Number	True vertical depth of sample (m)	Lithology	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Sub-Section (m)	Sub-Section Boundary Rationale
2115268	703.8	Banded schist	2.26	0.37	690-748	Gamma and gradient logs
2115269	816.5	Grey meta-sediment, folded quartz veins, minor schistosity	3.17	1.04	748-835	Gamma and gradient logs
2115270	891.2	Light grey, banded, schist	2.54	0.45	835-932	Gamma and gradient logs
2115271	1009.6	Schist, major quartz veining	2.19	0.16	932-1010	Gamma and gradient logs
2115272	1093.7	Banded, dark grey meta-sediment, medium grain, some pyrite	2.99	0.12	1010-1103	Gamma and gradient logs
2115273	1160.2	Schist with major quartz veining, originally claystone? iron staining, minor pyrite	2.41	0.42	1103-1173	Gamma and gradient logs

The modelled temperature data is plotted along with the measured temperature log in **Figure 25**. There is a reasonable agreement between the measured and modelled data, however as discussed above this was only achieved with the exclusion of data from the upper section of the log. The error in the heat flow determination is primarily due to the uncertainty associated with assigning a thermal conductivity measured from a limited size sample to a large sub-section of the log. Much of the error is due to the standard deviation of the measured values for sample 2115269. The variability of this sample is likely to be due to the presence of quartz veining; it is unknown whether this is representative of the sub-section. It is expected that the error would be reduced if there were a greater number of samples with thermal conductivity measurements and if there was a lithology log available.

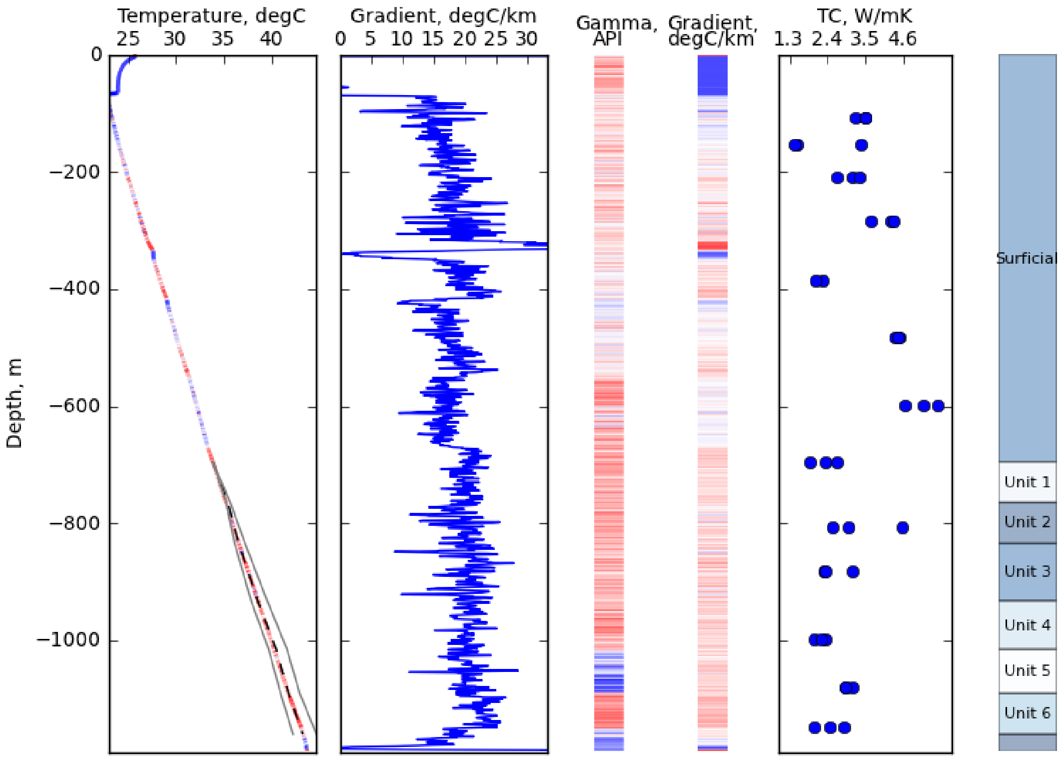

Figure 24: *Temperature log of well TTDD005 with the calculated gradient. The gamma log is also using a variable colour scale (blue (low) to red (high)) alongside another representation of the calculated gradient. Both these scales are purely relative and have been displayed in this fashion for the purpose of identifying the sub-section boundaries. The recorded logs are available in Electronic Appendix 2. The panel second from the right displays the thermal conductivity measurements with the values for each disc from each of the samples. On the far right is a representation of the geological model on which the heat flow determination is based.*

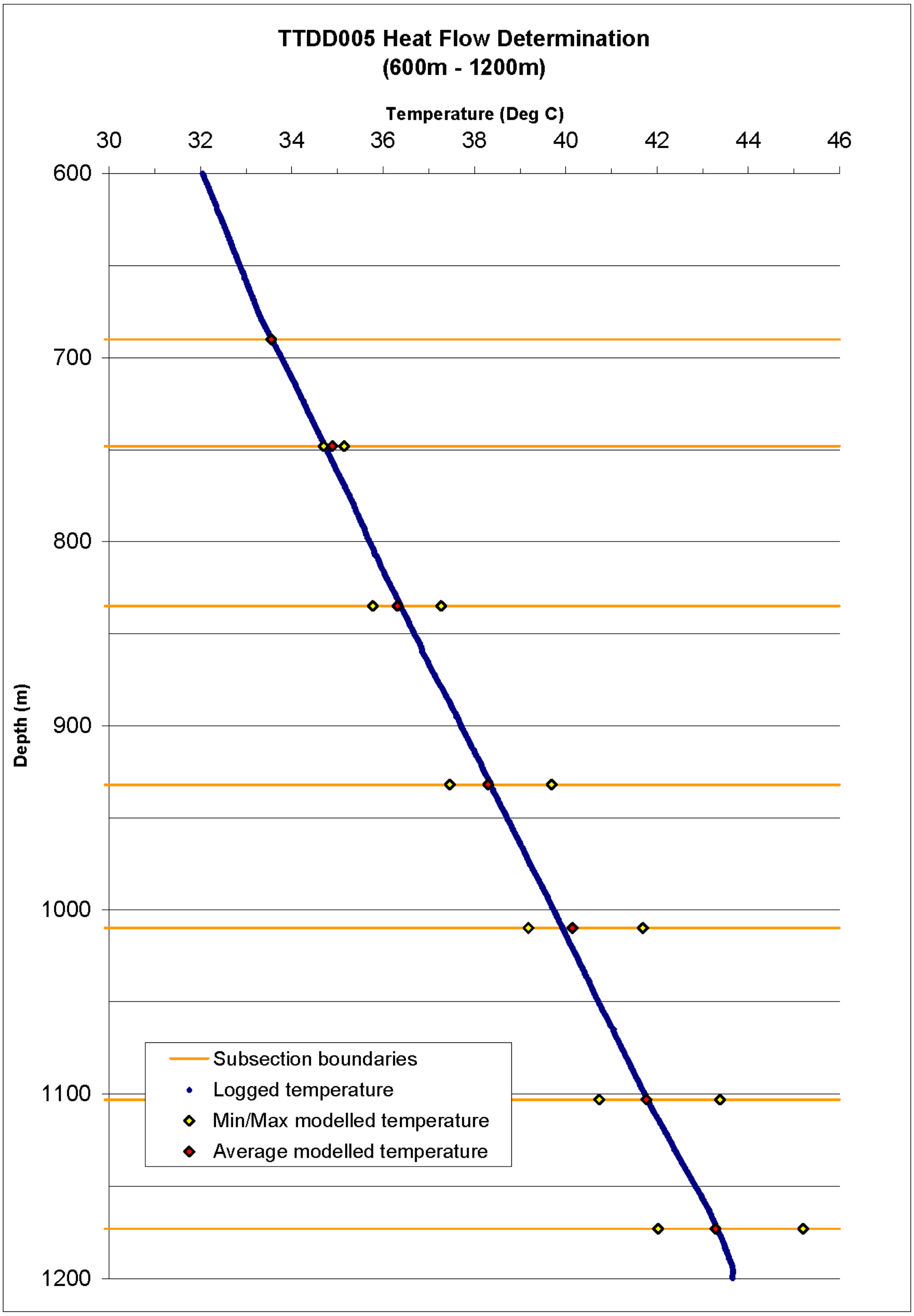

Figure 25: *Modelled and measured temperatures versus true vertical depth for TTDD0005. The sub-section boundaries are highlighted in orange. The modelled temperature at the top and bottom of each sub-section is highlighted in red (mean) and yellow (error bounds on the modelled temperature).*

Conclusions

The heat flow determinations included in this report are the fourth release of heat flow data from Geoscience Australia's Geothermal Energy Section. The collection of new temperature and thermal conductivity data is ongoing and more heat flow determinations will be released in the future. This data is making a significant contribution to improving the heat flow coverage of Australia. Future field work will be aimed at filling in the gaps in coverage to enhance the spatial distribution across the country. These data will improve the understanding of the thermal structure of the Australian continent and will be used as inputs to geothermal modelling and geothermal energy prospectivity analysis by Geoscience Australia in the future.

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