Western Australian Geothermal CENTRE OF EXCELLENCE

GeoTemp™ 1.0: User Manual

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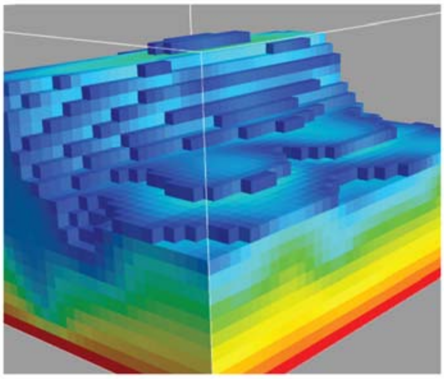

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EXECUTIVE SUMMARY

The evaluation of potential and resources during geothermal exploration requires accurate and consistent temperature characterization and modelling of the sub-surface. Existing interpretation and modelling approaches of 1D temperature measurements are mainly focusing on vertical heat conduction with only few approaches that deal with advective heat transport. Thermal regimes are strongly correlated to rock and fluid properties. Currently, no consensus exists on the methodology for identification of the thermal regime and the analysis of associated datasets. We developed a new framework allowing the identification of thermal regimes by rock formations, the analysis and modelling of wireline logging and discrete temperature measurements by taking into account the geological, geophysical and petrophysical data. This framework has been implemented in the GeoTemp software package that allows the complete thermal characterization and modelling at the formation scale and that provides a set of standard tools for the quality control, processing, interpretation of wireline and discrete temperature data. It enables the characterisation of thermal regimes, the calculation of vertical heat flow for conductive systems, the prediction of temperature at greater depths and the estimates of average temperature at target reservoir depths.

GeoTemp operates via a user friendly graphical interface written in Matlab that allows semi-automatic calculation, display and export of the results. Output results can be exported as Microsoft Excel spreadsheets or vector graphics of publication quality. GeoTemp™ is illustrated here with an example geothermal application from Western Australia and can be used for academic, teaching and professional purposes.

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1. INTRODUCTION

Temperature measurements are fundamental inputs (Prensky, 1992; Anderson, 2005; Bearsdmore and Cull, 2001) to many areas of hydrogeology, geodynamics, petroleum and geothermal studies (e.g. hydraulic properties estimation, heat flow prediction, petroleum generation, well completions and cementing, fluid production, performance monitoring, heat in place and stored heat calculations). For geothermal studies, accurate knowledge of static formation temperatures and thermal parameters at depth within a potential reservoir is necessary to evaluate reservoir potential, to calculate geothermal resources and reserve estimates but also to design plant and future field developments (Kohl et al., 2005).

The main sources of temperature measurements are petroleum exploration formation evaluation and groundwater drilling/monitoring programs. The deepest subsurface temperature data are available from petroleum exploration and production wells. Several petroleum temperature databases exist for Australia (e.g. PressurePlot (CSIRO, 2007) or OzTemp (Holgate & Gerner, 2010). However, in that case the measurements can be discrete (available at a given depth only) and unreliable due to measuring conditions (disturbance due to drilling and measurement of the mud temperature instead of the formation temperature; Deming, 1989; Beck and Balling, 1988). The processing and correction of mud temperature measurements to formation temperature has been extensively studied in the literature (Santoyo, 1997). The lack of information during and after drilling and the inaccuracy of measurements lead to great uncertainties in the estimation of equilibrated formation temperature (also called static formation temperature or true formation temperature). Uncertainties associated with discrete temperature measurements are often in the order of 15% (Beck & Balling, 1988). In addition, due to the specific target criteria applying in petroleum exploration, thermal data can be collected at locations distant from the geothermal exploration site leading to large extrapolation uncertainties. Shallower temperature measurements can be used for the subsurface thermal characterization and can be combined with knowledge on the deep formations to model temperature at greater depths.
In contrast, continuous measurement of temperature (via wireline logging) at regular spacing (usually better than 50 cm vertical resolution) provides useful statistics for steady-state formation temperatures. These measurements are rare for petroleum exploration and production wells but are more commonly acquired during groundwater studies. The analysis of these temperatures can be used to evaluate the shallow geothermal potential of a region (Kohl et al., 2005). The results can then be extrapolated to greater depths based on a local heat transfer model.

Heat is transported inside rocks by a combination of processes including conduction (i.e. transfer of energy between bodies as a result of temperature gradient) and advection (i.e. transfer of energy via the movement of a fluid phase, including buoyancy-driven convection). While convection is believed to be the dominant heat transfer mechanism in the Mantle, conduction is dominant in the Crust (Bearsdmore and Cull, 2001). Water movement within the rock can result in heat transfer by advection (including buoyancy-driven advection) and can represent a non negligible part of heat transfer near the surface (Haenel and Stegena 1988). The concept of thermal regime refers to the dominant heat production and heat transfer mechanism in the area of interest. Most geothermal studies assume a vertical heat conduction transfer with or without heat production for the interpretation of temperature measurements with a minority of studies considering vertical and/or lateral advection (Kukkonen, 1995; Kukkonen and Clauser, 1994).

Rock formations have different lithological, petrophysical and hydrogeological properties that can impact differently on the local heat transfer. The dominant heat transfer mechanism is highly dependent on rock thermal (specific heat, thermal conductivity) and fluid flow properties and therefore varies in space and time as function of the local geology, hydrogeology (including groundwater abstraction/injection activities) and radiogenic heat production (resulting largely from the decay of U, Th and K isotopes).

The identification of the local thermal regime is the first step required prior to proceeding with its characterization which are used for temperature predictions. The choice of a thermal regime is critical for the temperature interpretation and predictions. Vertical heat conduction is commonly assumed for the entire well. In some rare cases, other types of thermal regimes (vertical and horizontal advection) are considered (Kukkonen, 1995; Kukkonen and Clauser, 1994) but not systematically. There is no existing workflow for associating thermal regime to lithology and for quantitatively differentiating a vertical heat conduction regime to other types of thermal regimes.
A careful process of temperature measurement, data evaluation and processing is required before an interpretation of the temperature data can provide estimates of thermal properties (eg. thermal conductivity, vertical heat flow). Based on this thermal characterization, temperature predictions can be extrapolated to greater depths. Several computer codes are available for the analysis of temperature measurements. Wooley (1980), Marshall and Bentsen (1982), Garcia et al. (1998), Espinosa-Paredes et al. (2001) propose software packages for transient predictions of bottom hole temperature (BHT). Santoyo et al. (2000) propose the STATIC_TEMP software package for the prediction of true formation temperature (TFT) using bottom hole temperature (BHT) measurements and analytical solutions. Vertical conduction thermal modelling of crustal geotherms has been addressed recently by Leonardo (2011) and by Srivastava et al. (2009) while vertical advection and Peclet analysis has been studied by Hartmann and Rath (2005) and references therein. However, these tools do not allow the identification of thermal regimes or the evaluation of consistency/inconsistency between the interpretation of the observations and subsequent thermal profile modelling. To date, no software is available for the identification of thermal regimes and for the practical joint interpretation of wireline temperature measurements, formation thermal characterization, and temperature prediction and modelling. In order to fill this gap, the GeoTemp™ software package was specifically designed to address: (i) the temperature data processing, assessment and visualization; (ii) the identification of the vertical conduction thermal regime; (iii) the vertical heat conduction thermal characterization and; (iv) the prediction/extrapolation of temperature to greater depth based on existing steady well data.

This user manual is divided into nine sections; the following eight sections are organized as follows:

Section 2 surveys the existing knowledge of thermal characterization and available software.

Section 3 presents the software requirements and installation details.

Section 4 describes the main 'GeoTemp 1.0' interface.

Section 5 presents in detail the different modules and interfaces of the wireline interpretation workflow.

Section 6 describes the wireline workflow toolbox interfaces and modules

Section 7 provides details on the interface for discrete temperature measurements visualization and interpretation.
Section 8 gives a description of the input and output file formats.
Section 9 provides several examples and examples to help the user to become familiar with the software.

2. THEORETICAL BACKGROUND

The heat transfer in a porous medium such as the upper crust can be written in the form of a temperature-based equation (Saar 2011) taking into account the transfer of heat by conduction, dispersion, advection by flowing ground water and production by internal heat sources (such as the decay of radiogenic U, Th, K isotopes) as follows:

$$\frac{\partial}{\partial t}\left(\phi\rho_f c_f T + (1-\phi)\rho_s c_s T\right) = \nabla.\left(\frac{\rho_f c_f T}{\mu_f}\mathbf{k}\nabla\left(P+\rho_f gz\right)\right) + \nabla.\left(\boldsymbol{\lambda}_{\mathbf{m}}\nabla T\right) + S \qquad (1)$$

where T is the temperature, ϕ is the porosity, ρ is the density, c is the specific heat, μ is the dynamic viscosity, k is the permeability, λ is the thermal conductivity, t is the time, P is the pressure, g is the gravity constant, z is the distance along the vertical direction and S accounts for the heat sinks or sources. The subscripts f, s and m denote fluid, solid and mixed fluid-solid properties, respectively. In this equation, the thermal conductivity of the rock and fluid medium λ_m is assumed constant and the transfer of heat between liquid and solid phases is assumed to be instantaneous.
Assuming steady state heat transfer (equation 1) simplifies to:

$$\nabla.\left(\frac{\rho_f c_f T}{\mu_f}\mathbf{k}\nabla\left(P+\rho_f gz\right)\right) + \nabla.\left(\boldsymbol{\lambda}_{\mathbf{m}}\nabla T\right) = -S \qquad (2)$$

In a steady-state conductive vertical heat transfer without heat production, the conductive vertical heat flow (Q_z in W m^{-2}) is given by

$$Q_z = \lambda_m \frac{\partial T}{\partial z} \qquad (3)$$

where λ is the thermal conductivity of the local lithology (W m^{-1} K^{-1}) and $\partial T/\partial z$ is the thermal gradient within the formation (K m^{-1}). In the later conditions, the distribution of temperature versus depth is thus linear.

2.1 Identification of thermal regimes

In our proposed temperature characterization framework, the first step towards the identification of the thermal regimes is the evaluation of heat production by radiogenic decay of U, Th and K. U, Th and K which can be abundant in igneous and metamorphic rocks leading to non-negligible heat production. In contrast, in sediments, the rate of heat generation is considered negligible and is not considered in the calculation (Beardsmore and Cull, 2001).
The estimation of heat production rate in a given rock type or formation can be calculated by using gamma ray wireline log measurements following the empirical equation described below (Bucker and Rybach 1996):

$$A = 0.0158(GR - 0.8) \quad (4)$$

where A is the heat generation count in μW m^{-3} and GR is the gamma ray count in American Petroleum Institute (API) units.

Once the radiogenic heat production has been assessed, apparent vertical conduction is the most easily identifiable thermal regime and can be quantified directly from vertical thermal conductivity and steady-state wireline temperature measurements. If thermal conductivity is constant within each formation, the temperature profile exhibiting conductive heat flow will have linear segments by formation within the well. Similarly, an apparent vertical conduction thermal regime will lead to linear segments by formations on the wireline temperature profile.

For one dimensional, steady-state, conductive heat flow in a finite, layered medium with N layers and with negligible heat sources and sinks, the subsurface temperature $T(z)$ may be expressed as the following set of N contiguous linear profiles:

$$\begin{aligned} &T_1(z) = T_0 + q_0\, z / \lambda_1 && \text{for} \quad 0 \le z \le z_1 \\ &T_i(z) = T(z_{i-1}) + q_0 [z_i - z_{i-1}] / \lambda_i && \text{for} \quad z_{i-1} \le z \le z_i \quad \text{with} \quad i = 2, 3 \ldots N \end{aligned} \quad (5)$$

where T_0 is the surface temperature (°C), q_0 is the constant vertical heat flow (W.m^{-2}), λ_i is the thermal conductivity (W.m^{-1}.°C^{-1}) over the i^{th} depth interval [z_{i-1}, z_i], and z_i is the elevation of the i-th layer interface, measured in metres. The vertical coordinate z ranges from 0 (ground surface) to the total depth of the medium z_N. The quotient z_i / λ_i is formally identified with the thermal resistance of the i-th formation, while the quotient q_0 / λ_i is the temperature gradient of the i-th formation.

In a geothermal context, each depth interval is linked to a formation interval (i.e. the i-th depth interval corresponds to the i-th formation). As the conductive system assumes negligible heat sources and sinks, the vertical heat flow is constant throughout the domain. Temperature gradients are calculated using a numerical derivative of the temperature measurements and formation temperature gradients correspond to the arithmetic mean of the temperature gradient values within each formation. For each formation, the formation temperature gradient and the arithmetic average of the temperature measurements are used to generate a synthetic linear temperature profile. This synthetic temperature log (T_s) is then used along with the real temperature measurements (T_m) for the estimation of a relative error, $\varepsilon(z)$:

$$\varepsilon(z) = \left| \left(T_m(z) - T_s(z) \right) \big/ T_m(z) \right| \quad (6)$$

The vertical average of the relative error by formation, ε_i, provides a quantification of the fit of the temperature measurements by an apparent vertical conductive temperature regime. If the relative error is too large, the user may conclude that a vertical conduction thermal regime is not appropriate for the temperature measurements and the formation considered. Other types of thermal regime could be envisaged such as lateral conduction or vertical and horizontal heat advection. They are not developed further in this work.

Assuming that every formation relative error is acceptable and that formation thermal conductivity estimates are available, an apparent vertical heat flow can be calculated by formation

$$q_i = \lambda_i \nabla T_i \quad (7)$$

Where λ represents thermal conductivity, q is for heat flow and ∇T for the thermal gradient of the i^{th} formation.

Comparing those heat flow values within the entire well gives an understanding of the overall validity of the apparent vertical conduction assumption. When heat flow values by formation are different, a mean vertical heat flow can be calculated considering the thickness of each formation Δz_i

$$q = \frac{\sum q_i \Delta z_i}{\sum \Delta z_i} \tag{8}$$

In the case of an offset of the vertical heat flow, a heat flow correction q_{cor} can be calculated using the formation thermal conductivity difference between the thermal conductivity measuremenst λ_{real} and those inverted λ_{synth} .

$$\Delta\lambda_i = \lambda_{real\,(i)} - \lambda_{synth\,(i)} \tag{9}$$

$$\Delta q_i = \Delta\lambda_i \nabla T_i \tag{10}$$

$$\Delta q = \frac{\sum \Delta q_i \Delta z_i}{\sum \Delta z_i} \tag{11}$$

$$q_{cor} = q + \Delta q \tag{12}$$

An alternative is to estimate formation thermal conductivity from the temperature measurements and a vertical heat flow and assuming vertical conduction.

$$\lambda_i = \frac{q_i}{\nabla T_i} \tag{13}$$

2.2 Temperature modelling

The forward modelling of a steady-state temperature profile under an apparent vertical heat conduction process is described by equation 5. Using the previous characterization, a synthetic temperature profile can be computed. A reference temperature at a depth datum is required and can easily be extracted from a wireline measurement. A modelling relative error for each formation (i) can be defined using the synthetic results and the measurements

$$\varepsilon_i = \sqrt{\frac{\sum_{j=Top(i)}^{Bottom(i)} \left| T_{real(j)} - T_{synth(j)} \right|^2}{T_{top(i)} - T_{bottom(i)}}} \tag{14}$$

$T_{top\,(i)}$ and $T_{bottom\,(i)}$ are the temperature at top of the formation (i) and temperature at bottom of the formation (i), respectively. T_{real} is the real temperature and T_{synth} is the synthetic temperature.

2.3 Temperature prediction and associated uncertainties

The extrapolation and prediction of temperature at greater depth requires the characterization of the thermal regimes and the evaluation of thermal properties. Temperature predictions in an apparent vertical conduction thermal regime are described by equation 5. Formation boundaries and thermal conductivities of deeper formations are required.
To account for uncertainties in the formation thermal conductivities, three values of thermal conductivity are used: original, lower and upper values. Lower and upper estimates of thermal conductivities are estimated using lower and upper uncertainties. Lower and upper thermal conductivity, λ_{lower} and λ_{upper} respectively, are calculated with lower and upper uncertainty, ε_{lower} and ε_{upper} respectively. The subscript *i* stands for formation hint:

$$\begin{cases} \lambda_{lower(i)} = \lambda_i \left(1 - \varepsilon_{lower}\right) \\ \lambda_{upper(i)} = \lambda_i \left(1 + \varepsilon_{upper}\right) \end{cases} \tag{15}$$

Lower and upper estimates of heat flow are computed the same way. Lower formation temperature gradients are calculated assuming the lower estimate of heat flow and the upper estimates of thermal conductivity. Upper formation temperature gradients are calculated assuming the upper estimate of heat flow and the lower estimates of thermal conductivity. Formation temperature gradients are then used in equation 5 to calculate lower and upper geotherms.

3. GEOTEMP™ SOFTWARE PACKAGE

GeoTemp™ has a structured program design with logical tasks written in MATLAB using version 7.9 release 2009b. The software package provides a complementary set of tools for processing, interpretation and modelling via guided-user interfaces without the need of a third party software package. The graphical interfaces were designed to create a simple, intuitive and user-friendly interaction on a 1600x1200 screen resolution (minimum recommended screen resolution is 1280x1024). MATLAB was chosen as the computational engine due to its powerful data analysis capabilities and visualization features. The computer code is self contained into a main interface referred to as GeoTemp™ 1.0 (Figure 1) from which all modules can be accessed in separate interfaces allowing the user to evaluate, step by step, the consistency of the thermal analysis. The interfaces are mainly designed with buttons, tables and graphs. The data are loaded and inserted directly into tables and graphs. Intermediate results can be viewed in graphs in the interface before being displayed in a separate window for further quality control or reporting purposes. All modules accept widely used file formats such as Log ASCII Standard (LAS) files or Microsoft Excel spreadsheet files. Each module incorporates automatic procedures for loading and interpreting the data with visualization of intermediate and final results. Most of the results can then be exported either as a Microsoft Excel table or displayed as separate vector-based graphics. Results in tables can be copied/pasted into Microsoft Excel or exported as a Microsoft Excel file. Each graph can be saved into various formats (e.g. tiff, jpeg; eps or ai files) which can be included directly in reports or publications, or can be modified by the user using image processing software.

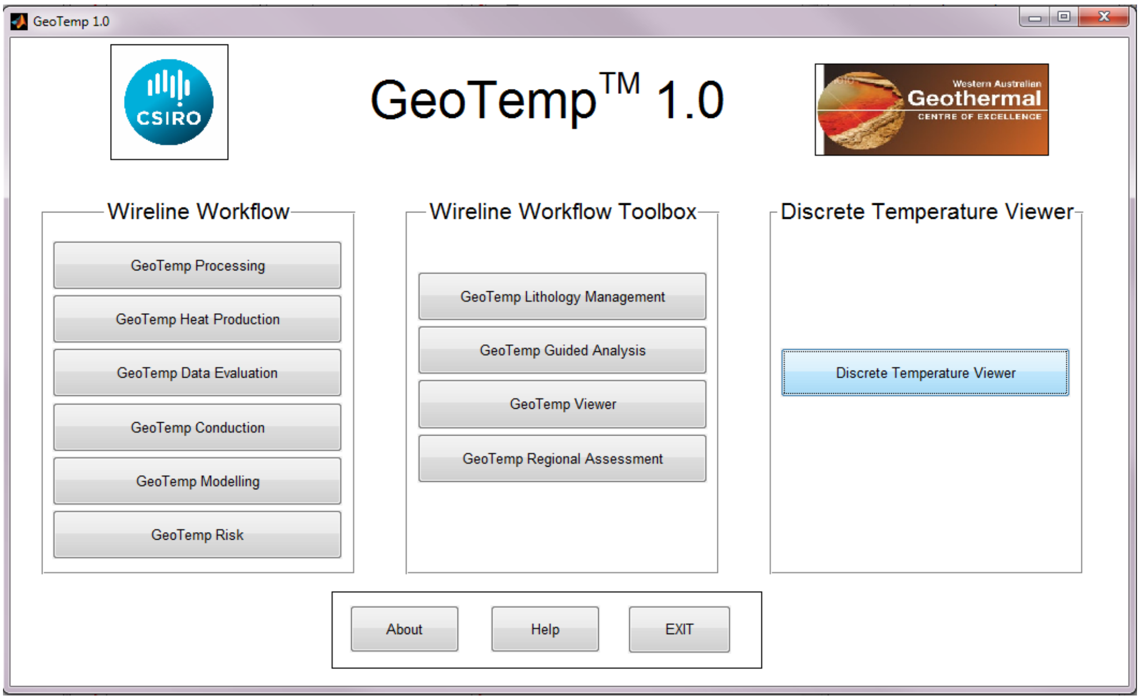


Figure 1: Screenshot of the 'GeoTemp 1.0' interface.

GeoTemp™ is platform independent software which can be run conveniently on Windows, Linux and Macintosh operating systems. The software package is composed of an executable file, some example examples and the detailed technical user manual. Executable files, examples and user manual can be downloaded free of charge from the CSIRO website (http://www.csiro.au/en/Organisation-Structure/Divisions/Earth-Science--Resource-Engineering/GeoTemp.aspx). The executable was created with the Matlab Compiler Toolbox 4.11 and uses a runtime engine referred to as the Matlab Compiler Runtime (MCR). In order to use the executable file, the user must have the MCR installed. The MCR is provided free-of-charge with the main MATLAB program and also available from the website: http://www.mathworks.com.au/products/compiler/mcr/index.html . The MCR is platform dependent. Note that the user should have administration rights on the machine to install the MCR.
Once the MCR is installed on your computer, copy the GeoTemp™ executable file (GeoTemp.exe) in your working folder and double-click on it to run the software.

GeoTemp™ proposes protocols for estimation of rock thermal parameters and prediction of underground temperature based on the analysis and interpretation of temperature logging, rock samples and discrete temperature measurements. GeoTemp™ guides this procedure along a well-defined workflow which is then easy to apply for the user. GeoTemp™ was built with three distinct components: (i) Wireline workflow, (ii) Wireline workflow toolbox and (iii) Discrete Temperature Viewer to enable the user to deal with wireline temperature log and discrete temperature measurements.

4. GEOTEMP™ INTERFACE

The following description is designed to give the reader a step by step overview of the program by highlighting the functionality of each feature presented.

To open the software, click on the 'GeoTemp.exe'. A window referred to as 'GeoTemp 1.0' is opening (Figure 2).

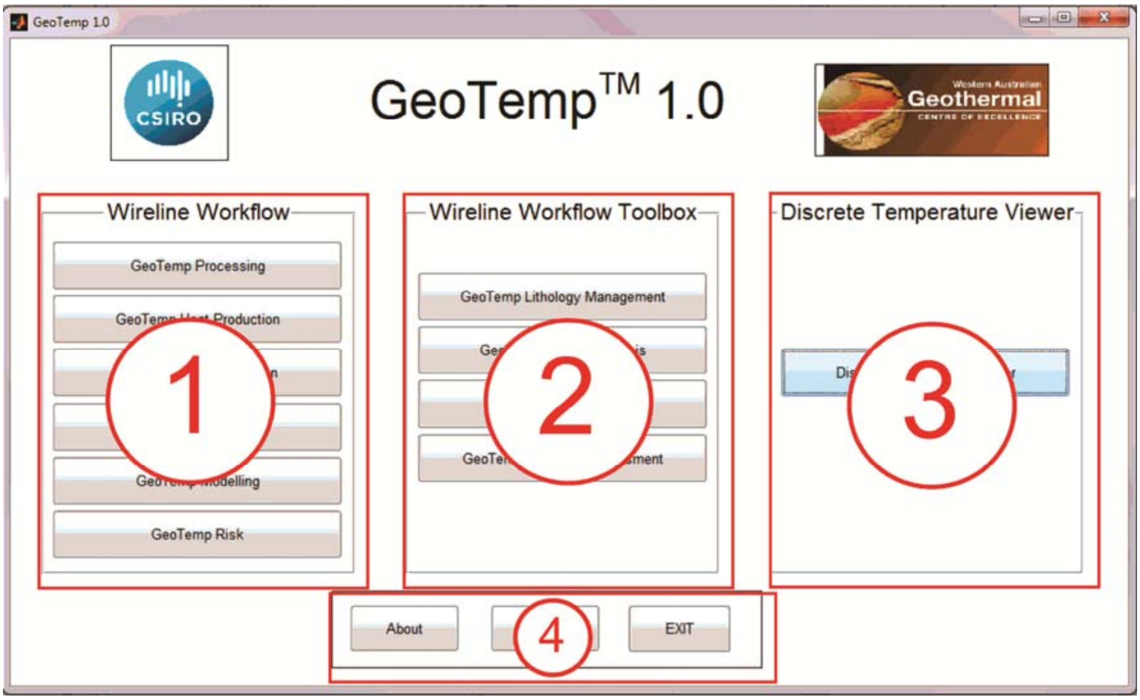


Figure 2: Screenshot showing the different panels of the 'GeoTemp 1.0' interface.

The window 'GeoTemp 1.0' is divided in four different panels (Figure 2).

- **Panel 1** refers to the 'Wireline Workflow' component, containing six buttons, for the direct interpretation of wireline temperature logs. The modules in this panel are explained in detail in section 5.

- **Panel 2** refers to the 'Wireline Workflow Toolbox' component, containing four buttons, and is the module to support the wireline workflow. The modules in this panel are explained in detail in section 6.

- **Panel 3** refers to the 'Discrete Temperature Viewer' component, containing one button, for the visualization and the interpretation of discrete temperature measurements. The modules in this panel are explained in detail in section 7.

- **Panel 4** contains three buttons:
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Contains the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

Note: The 'Help', 'About' and 'Exit' buttons are available in each window of the software and always have the same function.

5. WIRELINE WORKFLOW

The 'Wireline Workflow' component is subdivided into six different modules (Figure 2): (i) 'Processing', (ii) 'Data Evaluation', (iii) 'Heat Production', (iv) 'Conduction', (v) 'Conduction Modelling' and (vi) 'Risk'. These modules are linked together along the sequential process presented in Figure 4. These modules remain independent from each other and can be run separately.

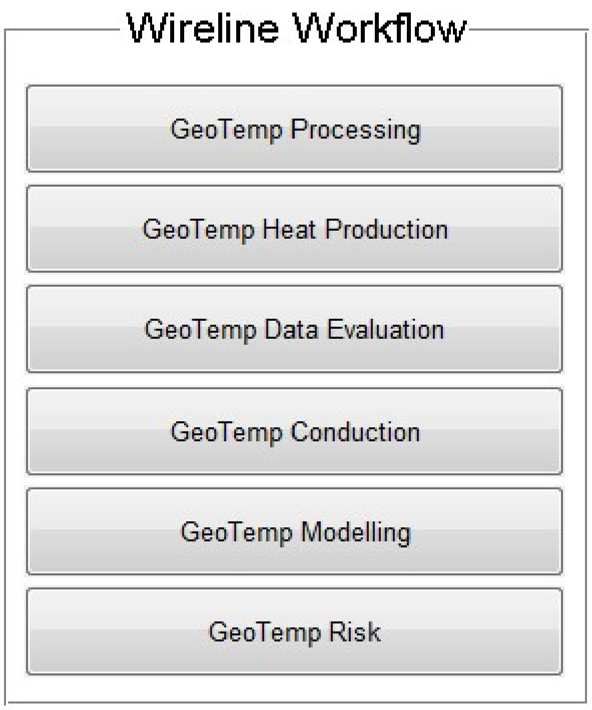


Figure 3: GeoTemp 1.0, Wireline Workflow frame.

5.1 Interpretation of wireline temperature logs

The interpretation of wireline temperature logging measurements is carried out by using the 'Wireline Workflow' and the 'Wireline Workflow Toolbox' components.

The 'Wireline Workflow' component presents a suite of six inter-connected modules for the processing and interpretation of wireline temperature logs (Figure 4). The 'Wireline Workflow' addresses the issues of data calibration, quality control, depth correction, heat production rate quantification, temperature gradient estimation (by rock formation), vertical conduction characterization, vertical conduction temperature modelling and prediction, and average reservoir temperature estimates with associated uncertainties.

Each module is independent from the others; however, they are all linked in an integrated framework that facilitates user navigation throughout the workflow from data processing to temperature predictions.

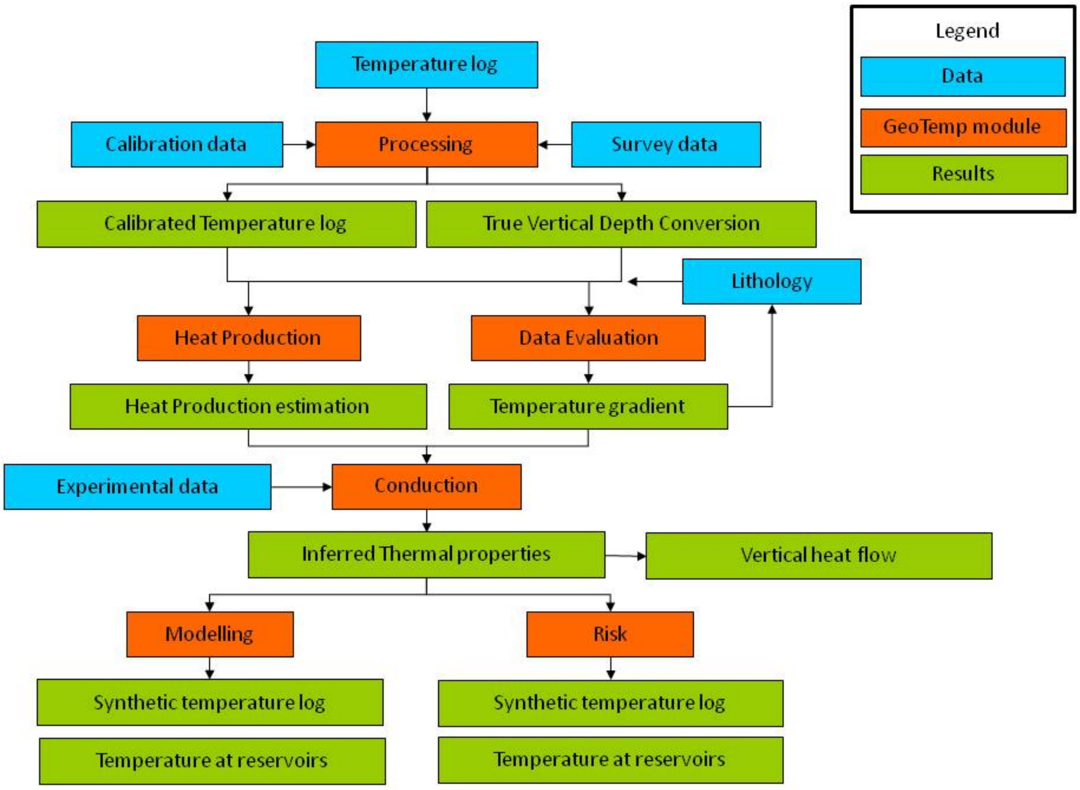


Figure 4: GeoTemp 1.0 wireline workflow framework for thermal reservoir characterisation. Blue boxes represent input data, orange boxes represent GeoTemp modules and green boxes represent module output data.

5.2 Processing

When launching the ‘GeoTemp Processing’ module from the ‘GeoTemp 1.0’ frame, the ‘GeoTemp Processing 1.0’ window appears (Figure 5).

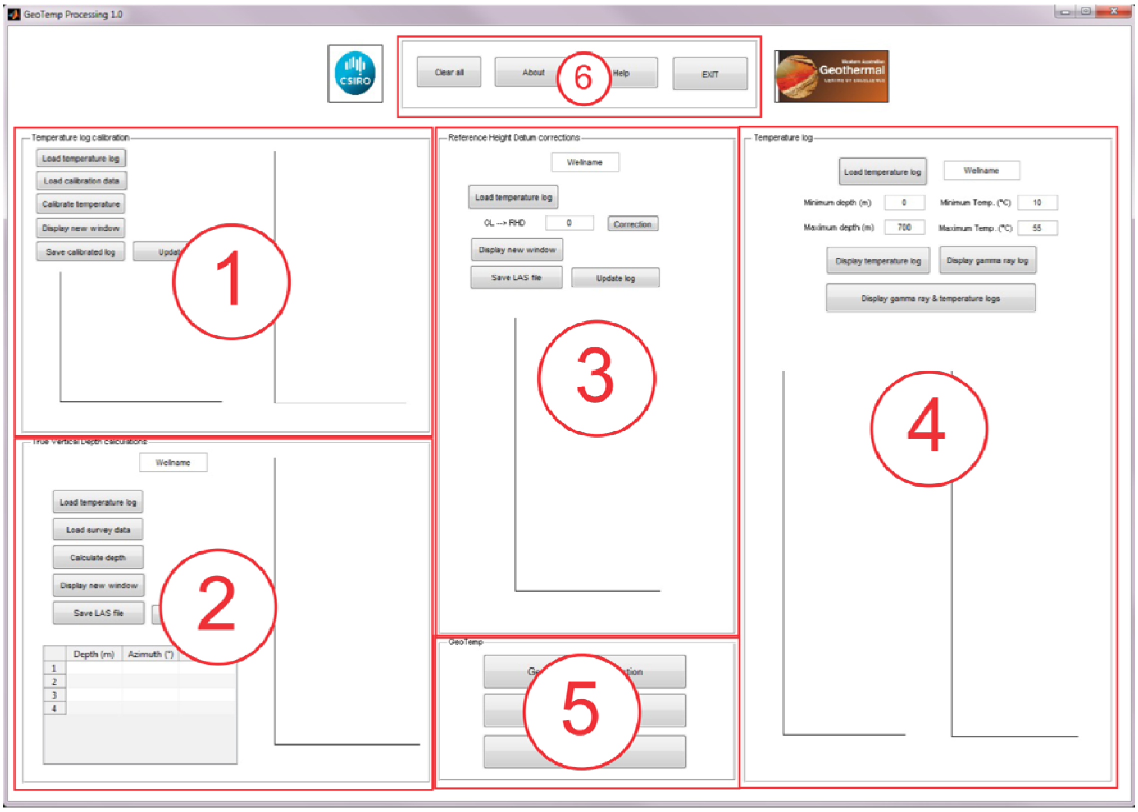


Figure 5: Screenshot showing the different panels of the 'GeoTemp Processing 1.0' interface.

In this window the user can:

- Calibrate a wireline temperature log (**Panel 1**)
- Convert measured depth (MD) to true vertical depth (TVD), (**Panel 2**)
- Correct the log for reference datum (**Panel 3**)
- Load a temperature and gamma ray log and visualize them (**Panel 4**).

Additionally, the window 'GeoTemp Processing 1.0' has two other panels (Figure 5).

- **Panel 5** contains three buttons to link this module to 'GeoTemp Heat Production 1.0', 'GeoTemp Data Evaluation 1.0' and 'GeoTemp Viewer 1.0'. If a dataset is available at the quality control stage, then this dataset is automatically transmitted to the 'GeoTemp Heat Production' or 'GeoTemp Data Evaluation'.

- **Panel 6** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

5.2.1 Temperature calibration

Temperature probes express the temperature in a unit such as counts per second (CPS), voltage or resistance which is probe dependent and could drift over time. Calibration of the temperature from the probe unit to temperature in degrees Celsius

(°C) is usually carried out using logging software. As new calibration data become available, the temperature logs would need to be recalibrated accordingly.

The temperature calibration element (**Panel 1**) of the 'GeoTemp Processing 1.0' module allows the calibration of wireline temperature logging measurements using a set of calibration data (probe unit versus °C) as input. Linear interpolation is used to apply the calibration data over the whole range of measurement data. The calibration dataset and the resulting temperature measurements are presented as two graphs (°C versus depth) in the interface.

To help with the calibration of wireline logs, 'GeoTemp Processing 1.0' allows the user to load a .LAS file containing the information on the wireline temperature log (Button 'Load temperature log'). The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text 'LAS file loaded' appears at the right of the button.

The second step of the calibration process is to load the calibration data (Button 'Load calibration data'). The format of the calibration file is described in details in section 8. Once performed, the text 'Calibration data loaded' appears at the right of the button. The calibration data (Temperature with respect to Count per second) appears in the bottom left graph of the frame.

The calibration of the wireline temperature log is performed by clicking the 'Calibrate temperature' button. The text 'Temperature calibrated' appears at the right of the button. The calibrated wireline temperature log with respect to depth appears in the right graph.

The button 'Display new window' enables the user to open the calibrated temperature log in a separate window where s/he can modify or copy the data or export the graph as a separate figure. The details of how to use the separate graph window are explained in section 8.

The button 'Save calibrated log' enables the user to save the newly calibrated temperature log in an LAS file format.

The button 'Update log' copies the calibrated temperature log to the other Panel of the Processing module as input data. The 'LAS file loaded' appears then at the right of each 'Load temperature log' button. The temperature and, if present, the gamma ray logs are displayed in the graph section of the wireline log quality control panel.

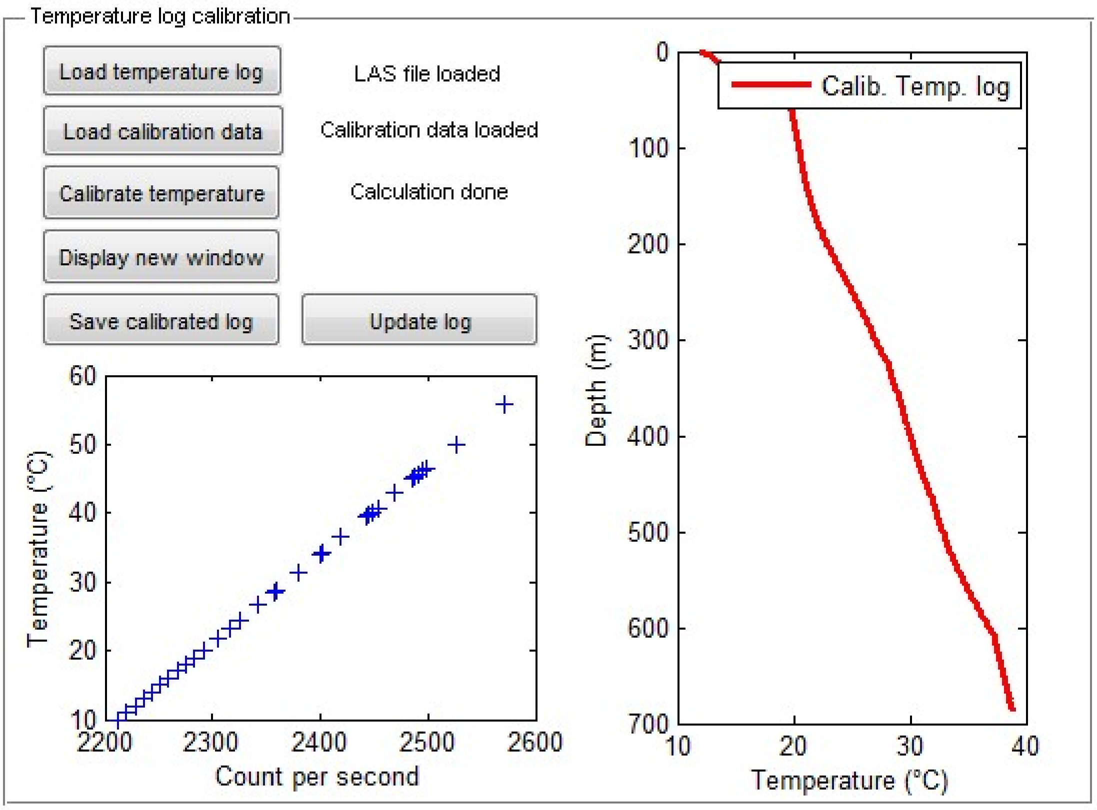


Figure 6: GeoTemp Processing, temperature calibration.

Technical details of the calibration:

To calculate a temperature measurement in degree Celsius from the temperature measurements in CPS, a linear interpolation curve is calculated between the two adjacent calibration points.

5.2.2 Depth correction

Wells are rarely perfectly vertical and hence the measured depth (MD) recorded during logging has to be converted into true vertical depth (TVD). The conversion from MD to TVD requires well survey data along with the wireline temperature logging file.

To help with the true vertical depth conversion of the wireline log, **Panel 2** of 'GeoTemp Processing 1.0' allows the user to load a .LAS file containing the information of the wireline temperature log (button 'Load temperature log'). The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text 'LAS file loaded' appears at the right of the button and the 'Name' of the well appears at the top of the frame.

The second step is to load the well survey data ('Load survey data' button). The well survey data file format is described in details in section 8. The details of the well survey data are then displayed in the table at the bottom of the frame. Once performed, the text 'Survey file loaded' appears at the right of the button.

The depth conversion from MD to TVD is achieved using the 'Calculate depth' button. Once performed, the text 'TVD calculated' appears at the right of the button and the graph of the right displays measured depth and true vertical depth with respect to measured depth. The button ‘Display new window’ enables the user to see the graph in a dedicated window. The details of how to use the separate graph window is explained in section 8.

The button ‘Save LAS file’ enables the user to save the newly calibrated temperature log in an LAS file format.

The button ‘Update log’ copies the converted TVD temperature log to the other panel of the processing module as input data. The ‘LAS file loaded’ appears then at the right of each ‘Load temperature log’ buttons. The temperature and, if present, the gamma ray logs are displayed in the graph section of the wireline log quality control panel.

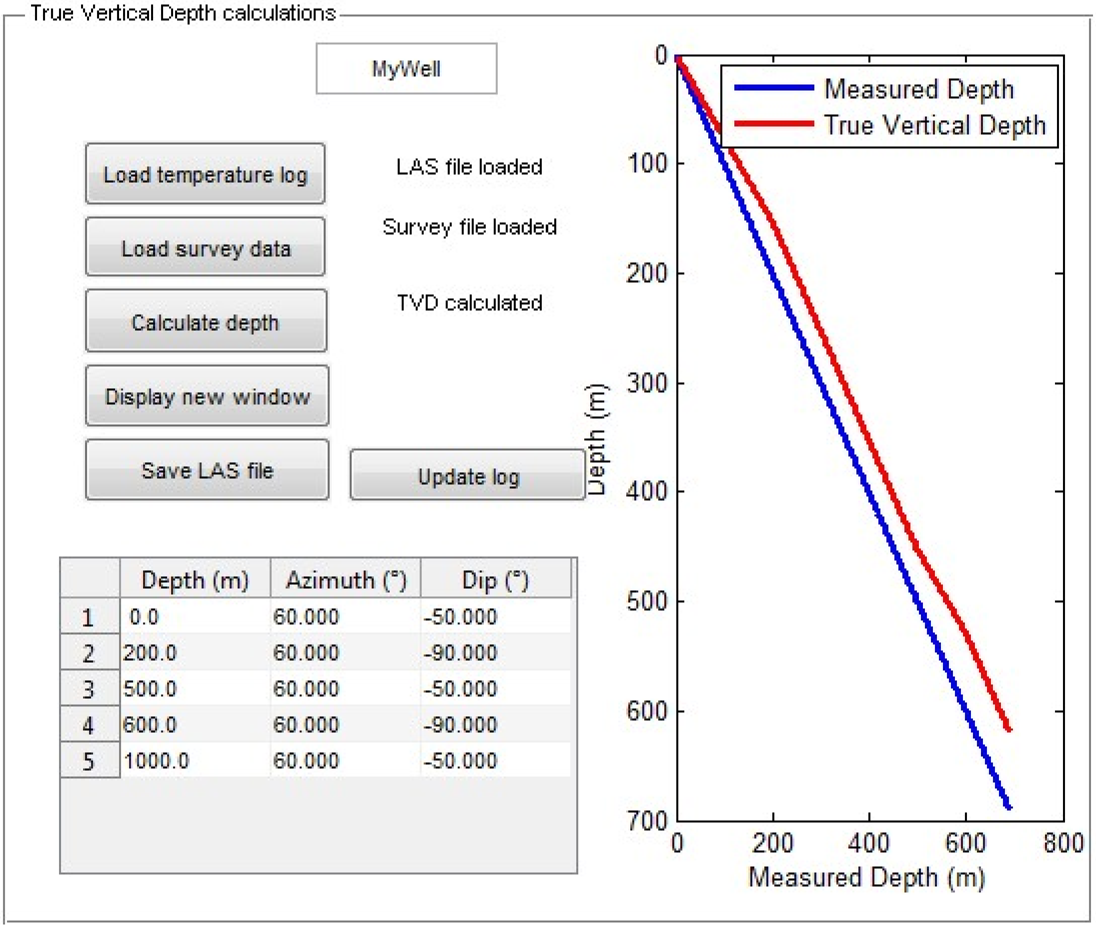


Figure 7: GeoTemp Processing, true vertical depth conversion.

<u>Technical details of the MD to TVD conversion:</u>

The depth conversion is calculated using the *‘Minimum Curvature Method’* (Mason and Taylor, 1971).

5.2.3 Reference datum corrections

Wireline temperature logs are often recorded using Kelly-Bushing or local ground level reference. When comparing wireline logs acquired at different wells, the reference datum needs to be corrected to the same reference, usually average sea level. It is the purpose of this feature to enable the user to do so.

The ‘Reference datum correction’ panel (**Panel 3**) is very similar to the previous one.

A ‘Load temperature log’ button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text ‘LAS file loaded’ appears at the right of the button and the ‘Name’ of the well appears at the top of the frame.

The second step is to specify the depth corrections in the edit box and to apply it to the log via the ‘Correction’ button. Both wireline temperature logs before and after the corrections are then displayed in the graph of the panel. Temperature GL refers to the temperature log before correction and Temperature RHD refers to the temperature after correction.

The button ‘Display new window’ enables the user to see the graph in a dedicated window. The details of how to use the separate graph window is explained in section 8.

The button ‘Save LAS file’ enables the user to save the newly calibrated temperature log in a LAS file format.

The button ‘Update log’ copy the calibrated temperature log to the other Panel of the Processing module as input data. The ‘LAS file loaded’ appears then at the right of each ‘Load temperature log’ buttons. The temperature and if present the gamma ray logs are displayed in the graph section of the wireline log quality control panel.

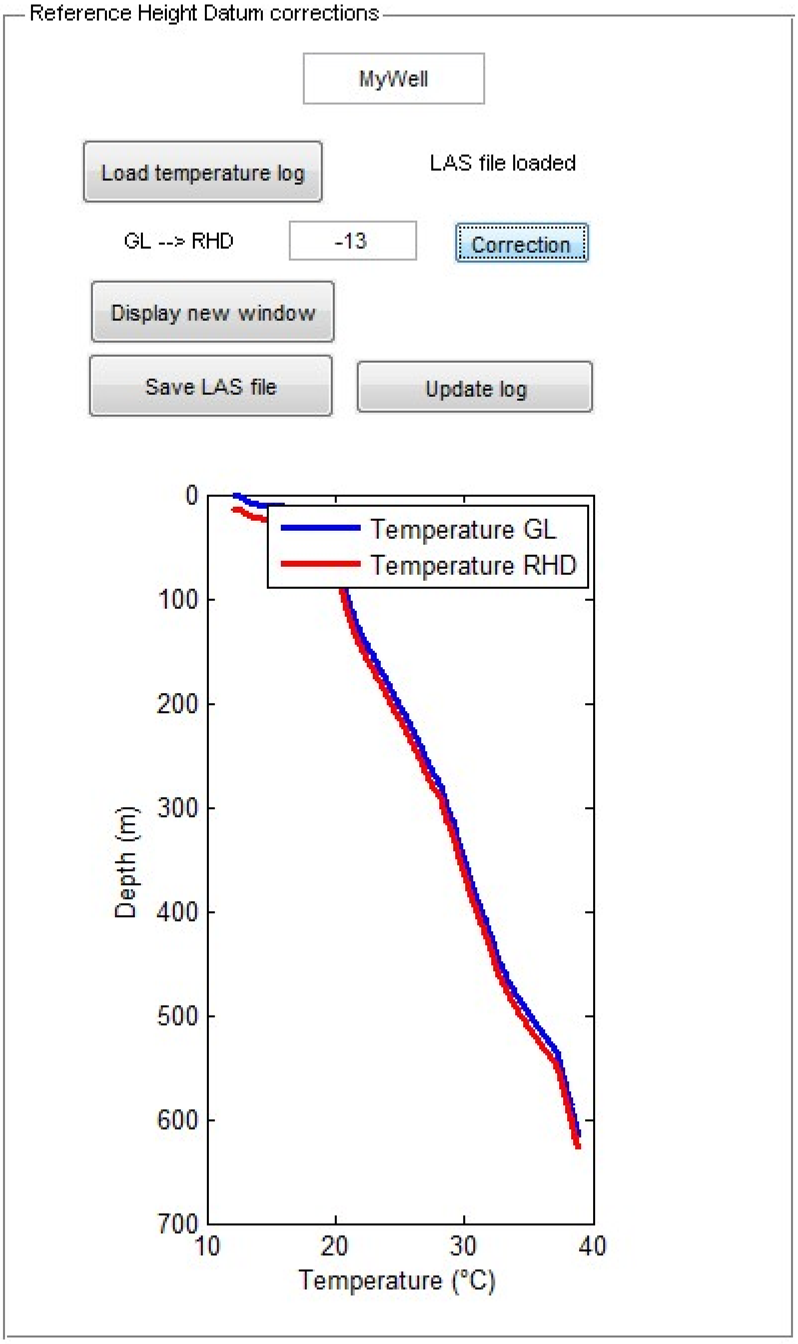


Figure 8: GeoTemp Processing, reference datum correction.

<u>Technical details of the reference datum correction:</u>
The correction is **added** to the measurement depth. For a shift from ground level (above sea level) to mean sea level, the correction would be negative.

5.2.4 Quality control of gamma ray and temperature logs

A visual investigation of wireline natural gamma ray and temperature logs is often a useful way to detect outliers and evaluate the first order quality of the measurement.

A ‘Load temperature log’ button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, and the ‘Name’ of the well appears at the top of the frame and the edit boxes below this button are populated with useful information, the graphs on the bottom part of the frame are updated with the temperature versus depth plot on the left and the gamma-ray graph on the right.

The button ‘Display temperature log’ opens a dedicated window displaying the temperature versus depth graph. Similarly, the button ‘Display gamma ray log’ opens a dedicated window displaying the gamma ray versus depth graph.
Finally, the button ‘Gamma ray & temperature logs’ enables a new window displaying the temperature and the gamma ray log with synchronized depth-axis in the same window.

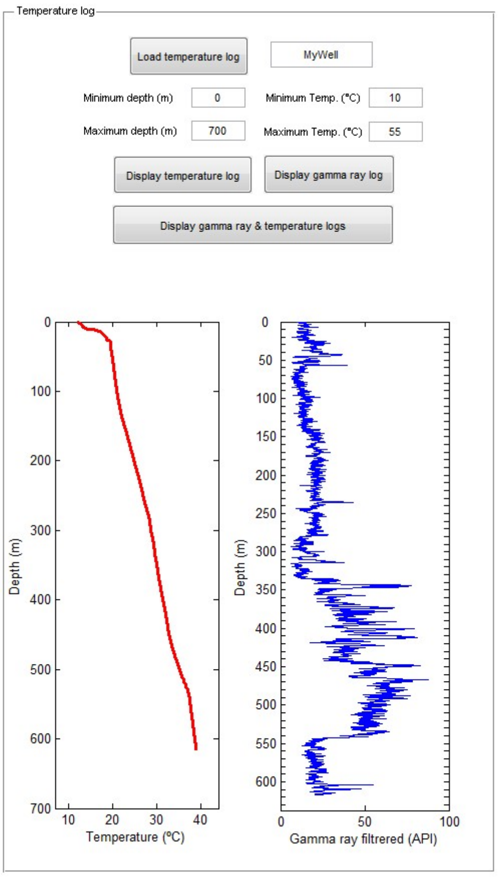


Figure 9: GeoTemp Processing, temperature log.

5.3 Heat Production

With the GeoTemp™ Heat Production module, the user can:
- Assess the quality of a wireline gamma ray logging measurement,
- Estimate a heat production rate log for the gamma ray log sampling interval,

- Estimate the heat production rate of encountered rock formations with associated basic statistics,
- Evaluate if the heat production rate of a rock formation is significant compared to the local vertical heat flow,
- Evaluate the vertical heat flow contribution due to the heat production for the entire depth interval of the well.

When launching this module from the ‘GeoTemp 1.0’ frame or from the ‘GeoTemp Processing’ module, the ‘GeoTemp Heat Production 1.0’ window appears (Figure 10).

The window ‘GeoTemp Heat Production 1.0’ is divided in five different panels (Figure 10).

- **Panel 1** refers to the ‘Heat Production’ panel where buttons for loading and processing of the data are located.

- **Panel 2** refers to the table presenting the results.

- **Panel 3** refers to the graphs presenting the wireline logs input and results.

Additionally, the window ‘GeoTemp Heat Production 1.0’ offers two other panels (Figure 10).

- **Panel 4** contains a button to link this module to ‘GeoTemp Data Evaluation 1.0’. If a dataset has been fully loaded, then this dataset is automatically transmitted to the ‘GeoTemp Data Evaluation’ module.

- **Panel 5** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

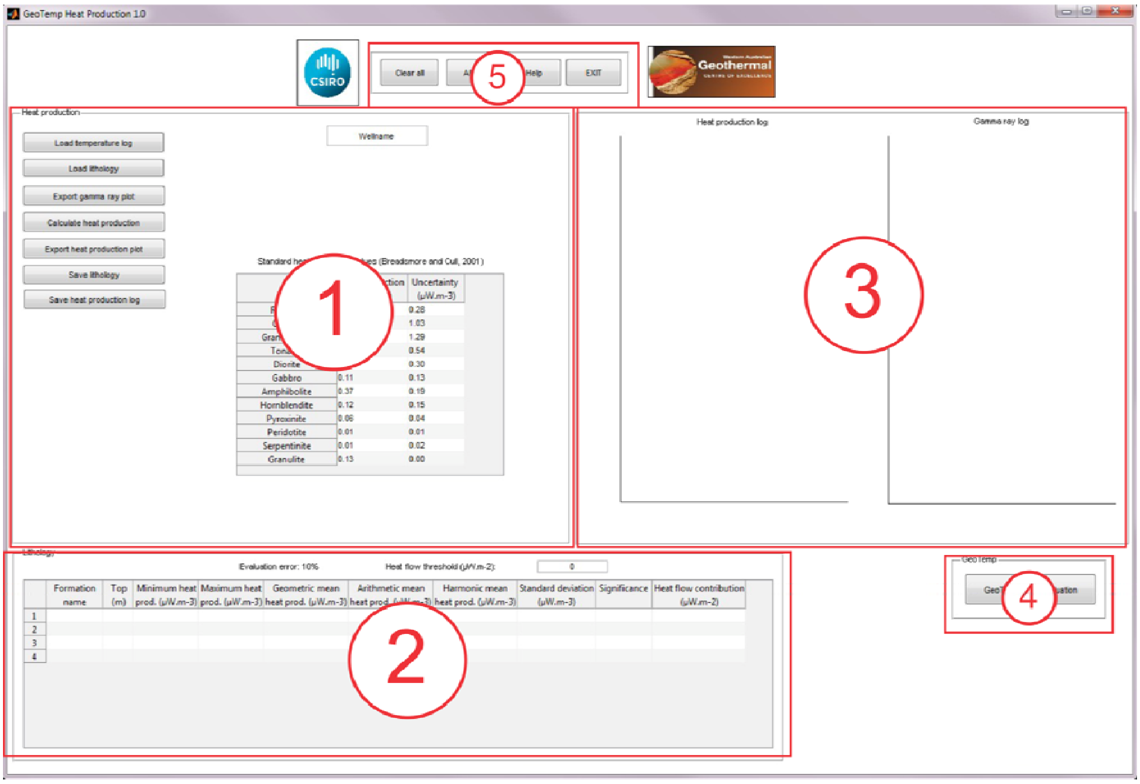


Figure 10: Screenshot showing the different panels of the 'GeoTemp Heat Production 1.0' interface.

Panel 1

A 'Load temperature log' button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text 'LAS file loaded' appears at the right of the button and the 'Name' of the well appears at the top of the frame. The gamma ray data are displayed in the graph in the right interface.

A 'Load lithology' button enables the user to load the lithology sequence at the well. The lithology data file format is described in details in section 8. The details of the lithology data are then displayed in the table at the bottom of the frame. The formation tops are then added to the graphs on the right. Once performed, the text 'Lithology loaded' appears at the right of the button.

The 'Export gamma ray plot' button opens a new window with the gamma ray log data that could be investigated via zooming features and be exported as graphics.

The 'Calculate heat production' button allows the user to calculate a heat production rate log and to display it in the left graph of Panel 3. Additionally, heat production rates are averaged by formations. Several key statistical data are presented for each formation in the bottom lithology table. Minimum and maximum values, geometric, arithmetic and harmonic means and standard deviation are presented in this table. The heat flow contribution of each formation is then calculated using the formation thickness and the harmonic average of the formation. The heat flow significance of a formation is indicated in the 'significance' column. If the formation's heat flow contribution is above the heat flow threshold then the significance is 1, else it is 0. The formation harmonic average of radiogenic heat rate is then added to the heat production log graph in red.

An ‘Export heat production graph’ button opens a dedicated window with the heat production log.

The ‘Save lithology’ button enables the export of the lithology data as presented in the table at the bottom of the frame. The details of the lithology file format are discussed in section 8.

A ‘Save heat production log’ button enables to save the wireline heat production log. The details of the data file format are discussed in section 8.

In addition, a table of standard rock heat production estimates from Beardsmore and Cull (2001) is provided as a comparison. Based on these results, the user can make assessments of the appropriateness of a heat production thermal regime.

Panel 2

This panel presents the results on the form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a formation within the lithology.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the minimum heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 4* contains the maximum heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 5* contains the geometric average heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 6* contains the arithmetic average heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 7* contains the harmonic average heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 8* contains the heat production standard deviation of the formation ($\mu W\ m^{-3}$).
- *Column 9* contains the significance w.r.t. heat production of the formation.
- *Column 10* contains the cumulated vertical heat flow due to radiogenic heat production by formation ($\mu W\ m^{-2}$).

Panel 3

This panel displays the wireline data as a result of interactions with Panel 1.

5.4 Data Evaluation

The ‘Data Evaluation’ module assists the user in the identification of the formation thermal regime. Once the wireline temperature log and lithology data are loaded, local and formation-averaged temperature gradients can be estimated by numerical differentiation and averaging by formation of the temperature log (by using either raw or moving-average filtered data). A visual quality control of the gamma ray, temperature and local temperature gradient versus depth by lithology or overall depth allows the user to check for inconsistencies. The user can adjust the lithology boundary locations if needed.
The simplest thermal regime is one-dimensional vertical heat conduction (see section 2 for details). In GeoTemp™, characterization of an apparent vertical heat conduction regime starts with the calculation of the temperature gradient locally and by rock formation. Temperature gradients are first calculated using a numerical derivative of the temperature measurements. Formation temperature gradients are calculated using the arithmetic mean of the temperature gradient values within each formation. Those values are reported in the lithology table. For a given formation, statistics on the local temperature gradient (e.g. geometric, arithmetic and harmonic means, median, standard deviation, minimum and maximum values) are displayed beside a histogram of the temperature gradients throughout the formation. The vertical average of the relative error by formation provides a quantification of the fit of the temperature measurements by a conductive temperature regime. If the formation averaged relative error is acceptable, the user may continue further the characterization via the ‘Conduction’ module. If the relative error is too large, the user may conclude that a vertical conduction thermal regime is not appropriate for the temperature measurements considered.

With the GeoTemp™ Data Evaluation module, the user can:
- Load and display a wireline temperature logging measurement with local lithology,
- Enables the user to extract temperature at top of formations and formation arithmetic average temperature,
- Calculate temperature gradient and visualize the results along with gamma ray and temperature measurements for the whole well, by formation or by user-defined intervals,
- Calculate several average formation temperature gradient, present statistics about them and display distribution histograms per formation,
- Evaluate the formation average temperature gradient and estimate the quadratic relative error to a vertical temperature gradient per formation,

When launching this module from the ‘GeoTemp 1.0’, ‘GeoTemp Processing’ or ‘GeoTemp Heat Production’ modules, the ‘GeoTemp Data Evaluation1.0’ window appears (Figure 11).

The window ‘GeoTemp Data Evaluation 1.0’ is divided into eight different panels (Figure 11).

- **Panel 1** presents the loading of the wireline temperature measurements with display of information such as associated name and total depth.

- **Panel 2** refers to the lithology management with features such as load, save and edit.

- **Panel 3** refers to the temperature gradient calculation and display of temperature wireline measurements.

- **Panel 4** proposes to view input data and temperature gradient results for the entire well, per formation or depth intervals.

- **Panel 5** presents the statistics associated with the temperature gradient calculation.

- **Panel 6** is the viewing panel for temperature and lithology data.

Additionally, the window ‘GeoTemp Data Evaluation 1.0’ offers two other panels (Figure 11).

- **Panel 7** contains a button to link this module to ‘GeoTemp Conduction 1.0’. If a dataset has been analysed, then this dataset is automatically transmitted to the ‘GeoTemp Conduction’ module.

- **Panel 8** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

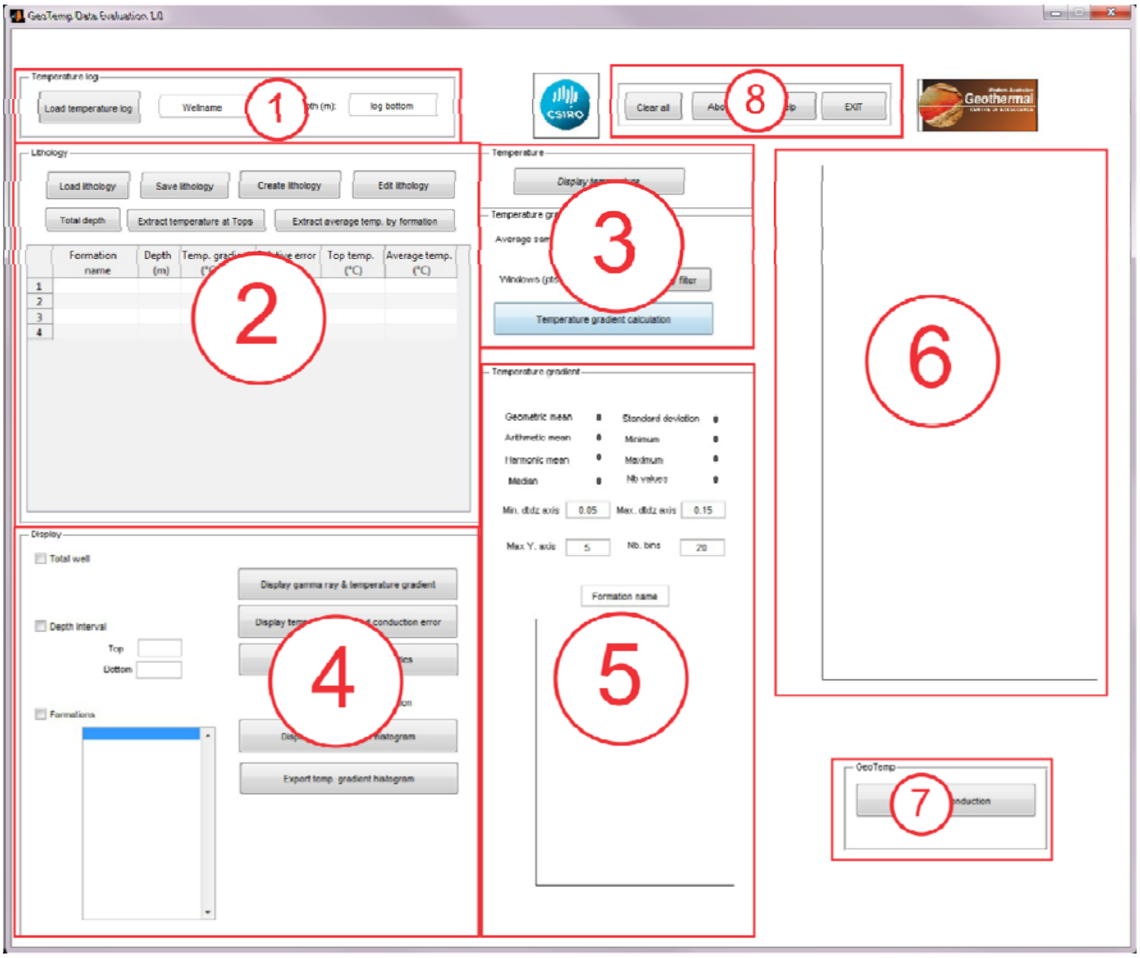


Figure 11: Screenshot showing the different panels of the 'GeoTemp Data Evaluation 1.0' interface.

Panel 1

A 'Load temperature log' button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text 'LAS file loaded' appears at the right of the button and the 'Name' of the well appears at the right of the button. The total depth of the wireline measurements is presented on the right of the button. The temperature data are displayed in the graph in the right interface. The average sampling interval in Panel 3 is also updated.

Panel 2

A 'Load lithology' button enables the user to load the lithology sequence at the well. The lithology data file format is described in details in section 8. The details of the lithology data are then displayed in the table under the button. The formation tops are then added to the graphs on the right.

The management of lithology is facilitated with the 'Save lithology', 'Create lithology' and 'Edit lithology' buttons. These buttons allow respectively saving, creating or editing a new lithology via the 'GeoTemp Lithology Management' module of the Wireline

Workflow Toolbox component. The detailed description of these features is presented in section 6.1.

The ‘Total depth’ button enables the user to add a formation at the bottom of the well ‘Total depth well’.

The ‘Extract temperature at Tops’ button enables the extraction of the temperature at the top of the formation. The results populate the 5th column of the table.

The ‘Extract average temperature by formation’ button enables the calculation of the arithmetic average of the temperature of each formation. The results populate the 6th column of the table.

This panel presents the results on the form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a formation within the lithology.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the temperature gradient inside the formation (°C km^{-1}).
- *Column 4* contains the temperature gradient calculation error for the formation.
- *Column 5* contains the temperature at top of the formation (°C)
- *Column 6* contains the arithmetic average temperature of the formation (°C).

Panel 3

The ‘Display Temperature’ button enables the user to display the temperature log in the graph on the right frame.

The average depth sampling interval is displayed in the panel following the loading of the wireline log data file.

The ‘Apply filter’ button enables the user to apply a moving average filter with a moving average window size specified in number of points. A window size ‘1’ does not apply any filtering. A window size ‘10’ will apply a moving average filter with associated length scale 10 multiplied by the sampling step.

The ‘Temperature gradient calculation’ button calculates numerically the temperature gradient at each point of the wireline temperature measurements. Formation average temperature gradients are calculated and displayed in the table of Panel 2. The quadratic error between the formation average temperature gradient and the temperature measurements is calculated by formation and added to the same table. The list of formations appears in the look-up table of Panel 4.

Panel 4

Three checkboxes provide the option to study and display results for the entire well depth interval, a specified depth interval or a formation interval.

The list of formations is proposed in the look-up table on the left of the panel once the temperature gradient calculation is performed.

The ‘Display gamma ray & temperature gradient’ button opens a new window (Figure 12) with the gamma ray, temperature and temperature gradient wireline log data for the checkbox selection (entire well, selected interval or formation interval). The logs can be investigated via different features as described in section 8 and be exported as graphics.

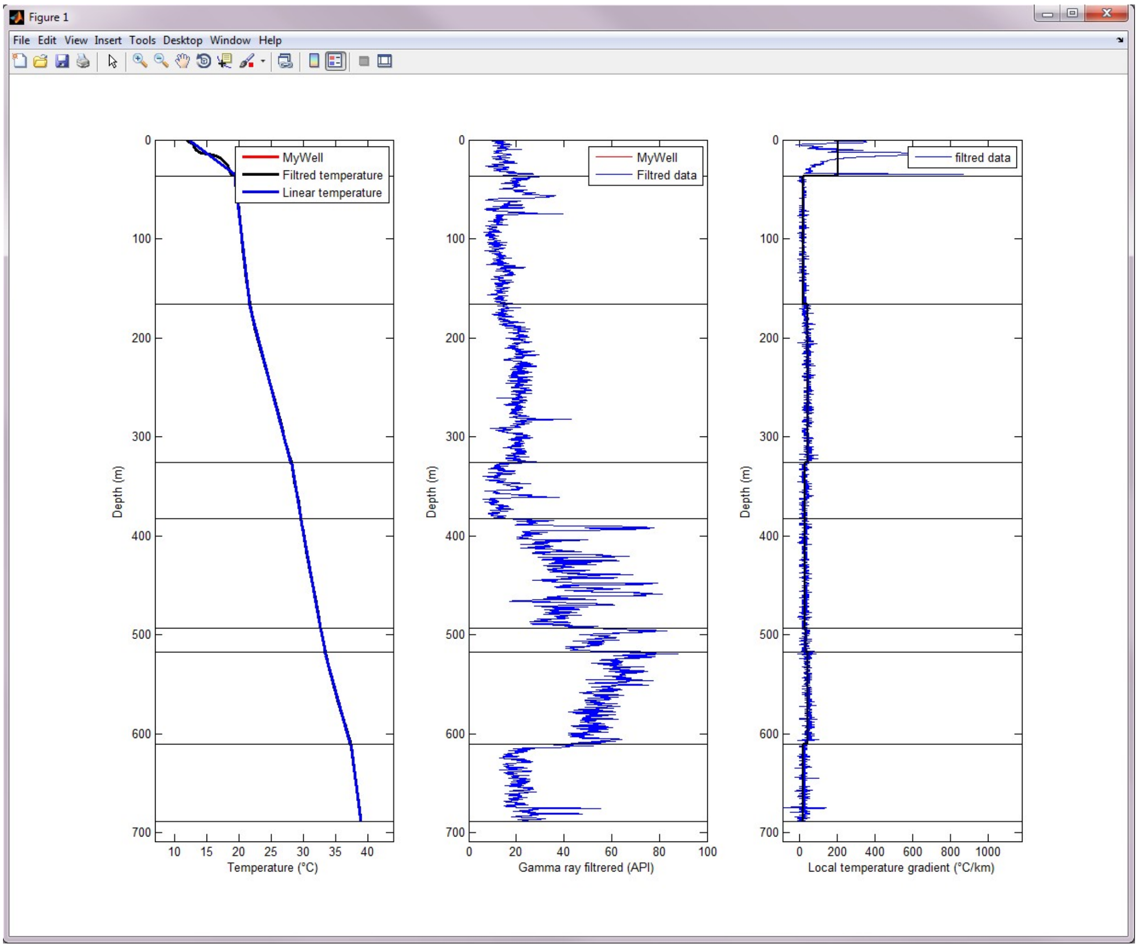


Figure 12: GeoTemp Data Evaluation, wireline log summary.

The ‘Display temperature log and conduction error’ button opens a new window with the temperature and errors to linear temperature gradient log data. The logs can be investigated via different features as described in section 8 and be exported as graphics.

The ‘Temperature gradient statistics’ button consider the depth interval checked for the statistical analysis on the temperature gradient and display the results in Panel 5.

The ‘Display temperature gradient histogram’ button opens a new window displaying the histogram analysis of the temperature gradient for the selected depth interval. The ‘probability density function’ checkbox enables the user to display a normal probability density function fitted to the temperature gradient distribution in the histogram graphs.

The ‘Export temperature gradient histogram’ button exports the temperature gradient values for the selected depth interval to an Excel spreadsheet.

Panel 5

This panel presents the results of a statistical analysis of the temperature gradient (Figure 13) for a depth interval under consideration. The analysis results are displayed after selection of a depth interval and clicking the 'Temperature gradient statistics' button in Panel 4.

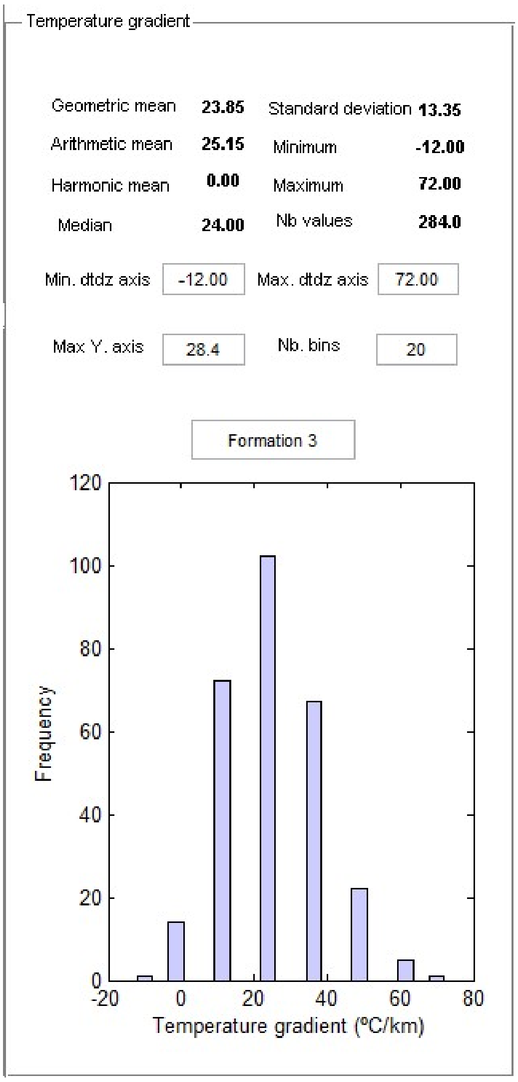


Figure 13: GeoTemp Data Evaluation, formation temperature gradient histogram.

Panel 6

This panel displays the temperature versus depth wireline data as a result of interactions with Panel 3.

5.5 Conduction

The 'Conduction' module assumes that a vertical heat conduction regime applies, and helps the user by providing a consistent interpretation of the vertical heat flow, thermal conductivities of formations and temperature measurements. In the 'Data Evaluation' module, formation temperature gradients have been estimated. Starting with these values and a value of vertical heat flow, thermal conductivities of formations can be evaluated by inversion. If estimates of formation thermal conductivities are available, they can also be loaded and used to estimate the vertical heat flow for each formation. From calculated formation heat flow values a best fit of those data is performed to provide a single heat flow value for the well and the formation thermal conductivities are recalculated accordingly. If the vertical averaged heat flow value is different from the assumed value, a correction is advised by the interface. As part of the vertical conduction interpretation, thermal conductivity versus depth, thermal resistance versus depth and temperature against thermal resistance (known as a Bullard plot (Bullard, 1939)) graphs can be displayed.

With the GeoTemp™ Conduction module, the user can:

- Load and display a wireline temperature logging measurement with local lithology,
- Load and display a lithological distribution of thermal conductivity,
- Calculate formation thermal conductivity using the formation temperature gradient and the vertical heat flow at the well,
- Load and compare thermal conductivity estimates and measurements with formation thermal conductivities,
- Estimate vertical heat flow based on formation thermal conductivities and temperature gradients,
- Calculate and display the thermal resistance, display a Bullard plot from the data.

When launching this module from the 'GeoTemp 1.0' or 'GeoTemp Data Evaluation' modules, the 'GeoTemp Conduction 1.0' window appears (Figure 14).

The window 'GeoTemp Conduction 1.0' is divided into eight different panels (Figure 14).

- **Panel 1** presents the loading of the temperature measurements with display of information such as associated name and total depth.

- **Panel 2** refers to the lithology management with features such as load, save and edit.

- **Panel 3** refers to the thermal conductivity and heat flow calculation from thermal conductivity measurements.

- **Panel 4** is the viewing panel for thermal conductivity and temperature data with associated lithology data.

- **Panel 5** is the interface to calculate heat flow from formation thermal conductivities.

- **Panel 6** gives the option to open new windows with temperature, thermal conductivity, thermal resistance and Bullard plot graphics.

Additionally, the window 'GeoTemp Conduction 1.0' offers two other panels (Figure 14).

- **Panel 7** contains two buttons to link this module to 'GeoTemp Conduction Modelling 1.0' and 'GeoTemp Risk 1.0'. If a dataset has been analysed, then this dataset is automatically transmitted to the appropriate module.

- **Panel 8** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

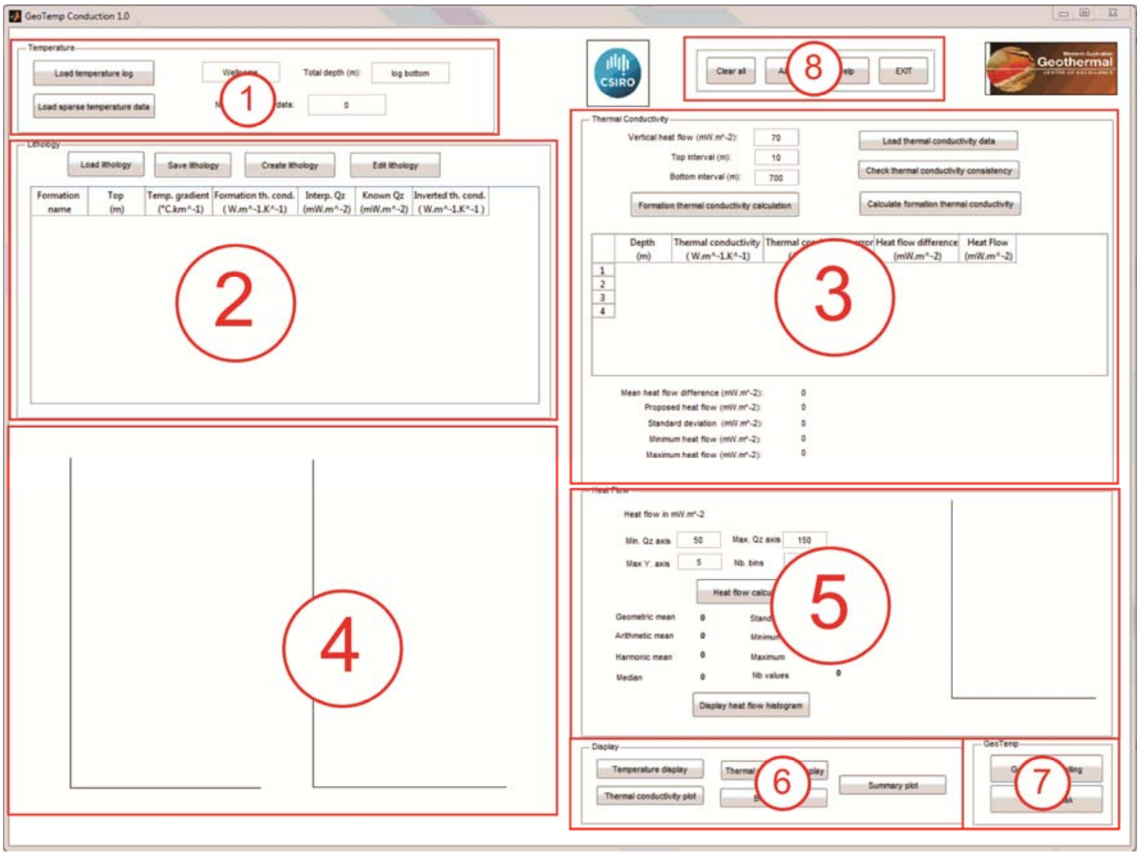


Figure 14: Screenshot showing the different panels of the 'GeoTemp Conduction 1.0' interface.

Panel 1

A 'Load temperature log' button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once

performed, the text ‘LAS file loaded’ appears at the right of the button and the ‘Name’ of the well appears at the right of the button. The total depth of the wireline measurements is presented on the right of the button. The temperature data are displayed in the left graph on Panel 4.
A ‘Load discrete temperature data’ button allows the user to load some discrete temperature data in the format described in section 8. The number of discrete temperature data appears on the right of the button. The temperature data are displayed in the left graph on Panel 4.

Panel 2
A ‘Load lithology’ button enables the user to load the lithology sequence at the well. The lithology data file format is described in details in section 8. The details of the lithology data are then displayed in the table under the button. The formation tops are then added to the graphs on the right.

The management of lithology is facilitated with the ‘Save lithology’, ‘Create lithology’ and ‘Edit lithology’ buttons. These buttons allow respectively saving, creating or editing a new lithology via the ‘GeoTemp Lithology Management’ module of the Wireline Workflow Toolbox component. The detailed description of these features is presented in section 6.1.

This panel presents the results on the form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a formation within the lithology.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the temperature gradient of the formation (°C km^{-1}).
- *Column 4* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$)
- *Column 5* contains the formation interpreted vertical heat flow ($mW\ m^{-2}$).
- *Column 6* contains the known formation vertical heat flow ($mW\ m^{-2}$).
- *Column 7* contains the inverted formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).

Panel 3
A ‘Formation thermal conductivity calculation’ button (Figure 15) enables the calculation of the formation thermal conductivity from the formation temperature gradient and the vertical heat flow specified in this panel. The top and bottom limit define the study interval.

A ‘Load thermal conductivity data’ button allows the user to load some discrete thermal conductivity measurements. The data populate the table of the panel.

A ‘Check thermal conductivity consistency’ button calculates the difference between the thermal conductivity calculated by formation and the thermal conductivity loaded by the user. The heat flow difference is also calculated as well as the heat flow. The arithmetic average of heat flow difference is then calculated and displayed below the table. A vertical heat flow is then proposed assuming the thermal conductivity values. The minimum, maximum values of vertical heat flow as well as the standard deviation are provided below the table. If the average heat flow difference is smaller than 1 mW m^{-2}, an ‘OK’ will be displayed below the table.

The ‘Calculate formation thermal conductivity’ button computes the formation harmonic averages of thermal conductivity which are then added to the lithology table.

This panel presents the results in form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a thermal conductivity input data point
- *Column 1* contains the depth (m).
- *Column 2* contains the thermal conductivity ($W\ m^{-1}\ C^{-1}$).
- *Column 3* contains the thermal conductivity difference ($W\ m^{-1}\ C^{-1}$).
- *Column 4* contains the vertical heat flow difference ($mW\ m^{-2}$)
- *Column 5* contains the vertical heat flow ($mW\ m^{-2}$)

Figure 15: GeoTemp Conduction, thermal conductivity and heat flow frame.

Panel 4

This panel displays the temperature and thermal conductivity versus depth wireline data as a result of combining results with those from Panel 1, 2 and 3.

Panel 5

A ‘Heat flow calculation’ button (Figure 16) allows the user, , to calculate the vertical heat flow for each formation, if a thermal conductivity is specified by formation in the

lithology (Panel 2). The associated statistics and a histogram are displayed in the panel.
The 'Display heat flow histogram' button opens a new window with the histogram of formation vertical heat flow.

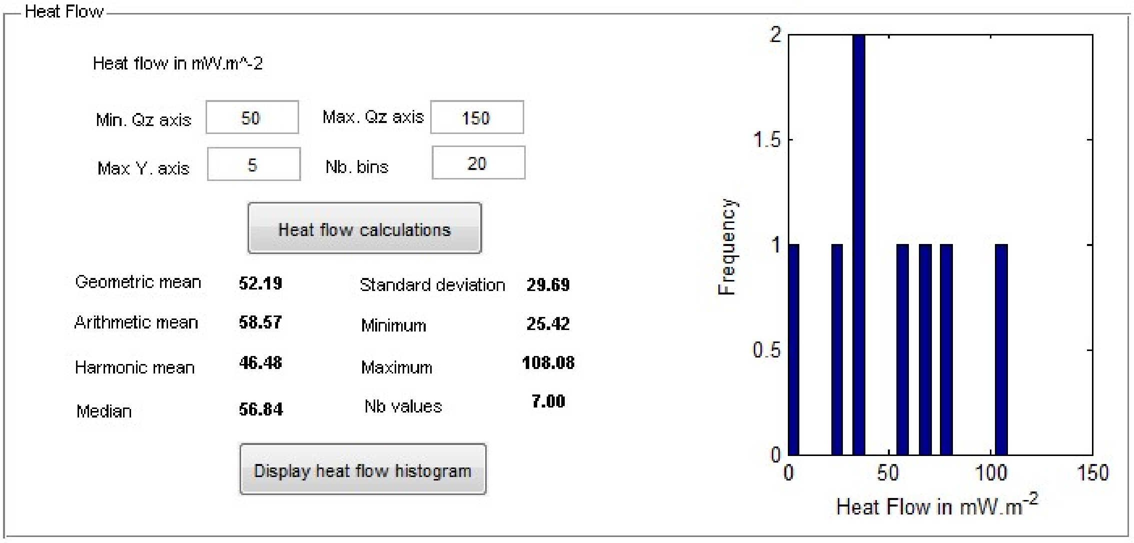


Figure 16: GeoTemp Conduction, vertical heat flow frame.

Panel 6

In this panel, each button opens a new window with a graph of the selected data: temperature, thermal conductivity or thermal resistance with respect to depth. The Bullard plot button opens a new window displaying the temperature as a function of the thermal resistance.

5.6 Conduction Modelling

Interpreted parameters such as formation thermal conductivities, vertical heat flow and temperature at a given depth are used to calculate a synthetic piecewise linear temperature log.
Temperature estimates can be calculated at depths greater than those measured if a vertical heat conduction regime is assumed. Drill core measurements, thermal conductivities of lithologies and discrete temperature data can be used to help in the interpretation and quality control of the vertical conduction modelling results. In addition, temperature estimates (average, bottom and top temperatures) in a reservoir can be calculated by either loading or manually entering depths of reservoir boundaries (i.e. top and bottom).

With the GeoTemp™ Conduction Modelling module, the user can:
- Load and display a lithology with associated thermal conductivity,
- Create a geotherm or temperature profile from formation thermal conductivity and temperature gradient,
- Compare the synthetic geotherm with the wireline temperature measurement and discrete temperature data,

- Compare the formation thermal conductivity with thermal conductivity measurements,
- Simulate a geotherm to greater depth using the vertical heat conduction assumption,
- Extract temperature at reservoir intervals,

When launching this module from the 'GeoTemp 1.0' frame or from the 'GeoTemp Conduction' module, the 'GeoTemp Conduction Modelling 1.0' window appears (Figure 17).

The window 'GeoTemp Conduction Modelling 1.0' is divided into nine different panels (Figure 17).

- **Panel 1** enables the loading of the lithology data with features such as load, save and edit.

- **Panel 2** refers to the vertical conduction temperature modelling.

- **Panel 3** is the viewing panel for thermal conductivity and temperature with associated lithology data.

- **Panel 4** refers to the loading of discrete thermal conductivity and wireline and discrete temperature data for validation purpose.

- **Panel 5** provides the option to extract temperature at top and bottom of a specific reservoir depth interval.

- **Panel 6** provides the option to assess the difference between the modelled temperature and the wireline measurements.

- **Panel 7** enables the user to display temperature and thermal conductivity graphics in new window.

Additionally, the window 'GeoTemp Conduction Modelling 1.0' offers two other panels (Figure 17).

- **Panel 8** contains a button to link this module to 'GeoTemp Risk 1.0'. If a dataset has been analysed, then this dataset is automatically transmitted to the 'GeoTemp Risk' module.

- **Panel 9** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

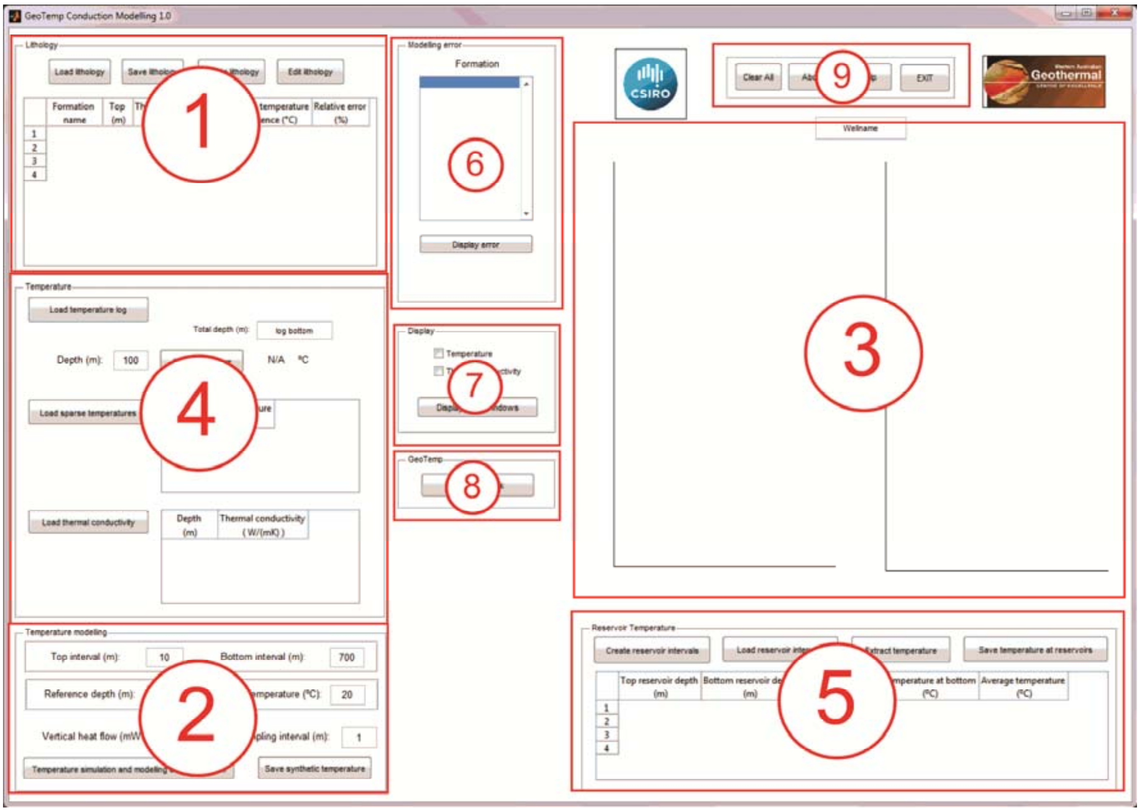


Figure 17: Screenshot showing the different panels of the ‘GeoTemp Conduction Modelling 1.0’ interface.

Panel 1
A ‘Load lithology’ button enables the user to load the lithology sequence. The lithology data file format is described in details in section 8. The details of the lithology data are then displayed in the table under the button. The formation tops are then added to the graphs on the right.

The management of lithology is facilitated with the ‘Save lithology’, ‘Create lithology’ and ‘Edit lithology’ buttons. These buttons allow respectively saving, creating or editing a new lithology via the ‘GeoTemp Lithology Management’ module of the Wireline Workflow Toolbox component. The detailed description of these features is presented in section 6.1.

This panel presents the data in form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).
- *Column 4* contains the temperature error (%).

Panel 2

A ‘Get temperature’ button allows the user to extract the temperature at the specified depth (on the left of the Button) from the wireline temperature log (see panel 4 for loading the wireline temperature log).

The ‘Temperature simulation’ button computes a synthetic temperature log from the formation thermal conductivity, the lithology and the vertical heat flow value (Figure 18). The synthetic temperature log is displayed in the right graph of panel 3.

The ‘Save synthetic temperature’ button enables the user to export the synthetic temperature log to a file.

The ‘Modelling error calculation’ button computes the error between the measurements and the synthetic temperature log. The error is estimated by formation and informs the lithology table in Panel 1. The results of this calculation can be investigated further via Panel 6.

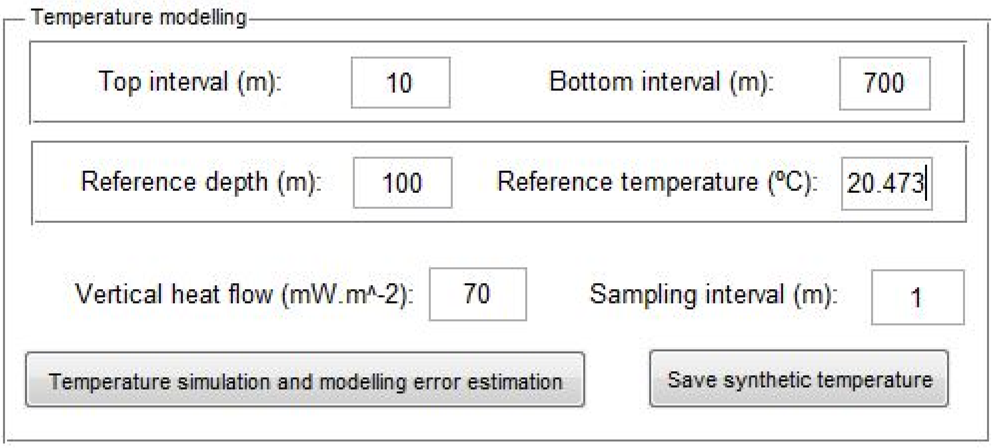


Figure 18: GeoTemp Conduction Modelling, temperature modelling.

Panel 3

This panel displays the temperature and thermal conductivity versus depth as a result of interactions with Panel 1, 2 and 4.

Panel 4

A ‘Load temperature log’ button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text ‘LAS file loaded’ appears at the right of the button and the ‘Name’ of the well appears at the right of the button. The total depth of the wireline measurements is presented on the right of the button.

A ‘Load discrete temperatures’ button allows the user to load some discrete temperature data in the format described in section 8. The discrete temperature data (depth of measurement and value) appears on the table below the button.

A ‘Load discrete thermal conductivities’ button allows the user to load some discrete thermal conductivity data in the format described in section 8. The discrete thermal conductivity data (depth of measurement and value) appears on the table below the button.

Panel 5

A 'Create reservoir intervals' button enables the user to create reservoirs by giving a top and bottom depth interval.

A 'Load reservoir intervals' button enables the user to load a file containing the reservoir depth interval.

The 'Extract temperature' button computes the temperature at top, bottom and reservoir average temperatures.

The 'Save temperature at reservoirs' button exports the reservoirs with temperature data to a file as described in section 8.

This panel presents the data in form of a table where:
- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a reservoir.
- *Column 1* contains the top reservoir depth (m).
- *Column 2* contains the bottom reservoir depth (m).
- *Column 3* contains the temperature at top reservoir depth (°C).
- *Column 4* contains the temperature at the bottom reservoir depth (°C).
- *Column 5* contains the average temperature of the reservoir (°C).

Panel 6

The 'Display modelling error' button opens a new windows and plots the quadratic temperature difference between the measurement and the simulated temperature versus depth for the selected formation in the look-up table of the Panel.

Panel 7

This panel enables the user to open new windows with temperature versus depth and thermal conductivity versus depth graphs according to the activated checkbox.

5.7 Risk

Uncertainties in vertical conduction parameters can propagate during temperature extrapolation and lead to large variations that must be taken into account in risk analysis. The 'Risk' module (Figure 5) is available from the 'Framework' interface or the 'Conduction' module and uses similar input to the 'Conduction Modelling' module, with additional information required on the vertical heat flow and formation thermal conductivity errors. Heat flow and its associated relative error and formation thermal conductivities with lower and upper percentage of error are used to generate lower and upper values of heat flow and formation thermal conductivities. For each formation, lower, median and upper temperature gradients are calculated using the above heat flow and thermal conductivity values. Finally, three temperature profiles (lower, median and upper) are calculated. The results are displayed as three different temperature logs and conductivity log with associated uncertainty (Figure 5). Temperature (and associated uncertainty) at a given depth can be extracted as well as the depth for a given temperature. Similarly, reservoir boundaries can be specified with temperatures and uncertainties calculated and extracted for the average reservoir and its lower and upper bounds.

With the GeoTemp™ Risk module, the user can:

- Load and display a lithology with formation thermal conductivity estimates and associated uncertainty,
- Simulate geotherms from formation thermal conductivity and temperature gradient with associated uncertainties,
- Compare the formation thermal conductivity with thermal conductivity measurements,
- Compare the geotherms with temperature measurements,
- Extract temperature at reservoir intervals.

When launching this module, by clicking the ‘GeoTemp Risk’ button in the ‘GeoTemp 1.0’ frame or from the ‘GeoTemp Conduction’ and ‘GeoTemp Conduction Modelling’ modules, the ‘GeoTemp Risk 1.0’ window appears (Figure 19).

The window ‘GeoTemp Risk 1.0’ is divided into 8 different panels (Figure 19).

- **Panel 1** enables the loading of the lithology data with features such as load, save and edit.
- **Panel 2** refers to the vertical conduction temperature modelling.
- **Panel 3** is the viewing panel for thermal conductivity and temperature with associated lithology data.
- **Panel 4** provides the option to extract temperature at a given depth and extract depth for a given temperature.
- **Panel 5** provides the option to extract temperature at top and bottom of a specific reservoir depth interval.
- **Panel 6** refers to the loading of discrete thermal conductivity and wireline and discrete temperature data for validation purpose.
- **Panel 7** enables the user to display temperature and thermal conductivity graphics in a new window.

Additionally, the window ‘GeoTemp Risk 1.0’ offers another panel (Figure 19).

- **Panel 8** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

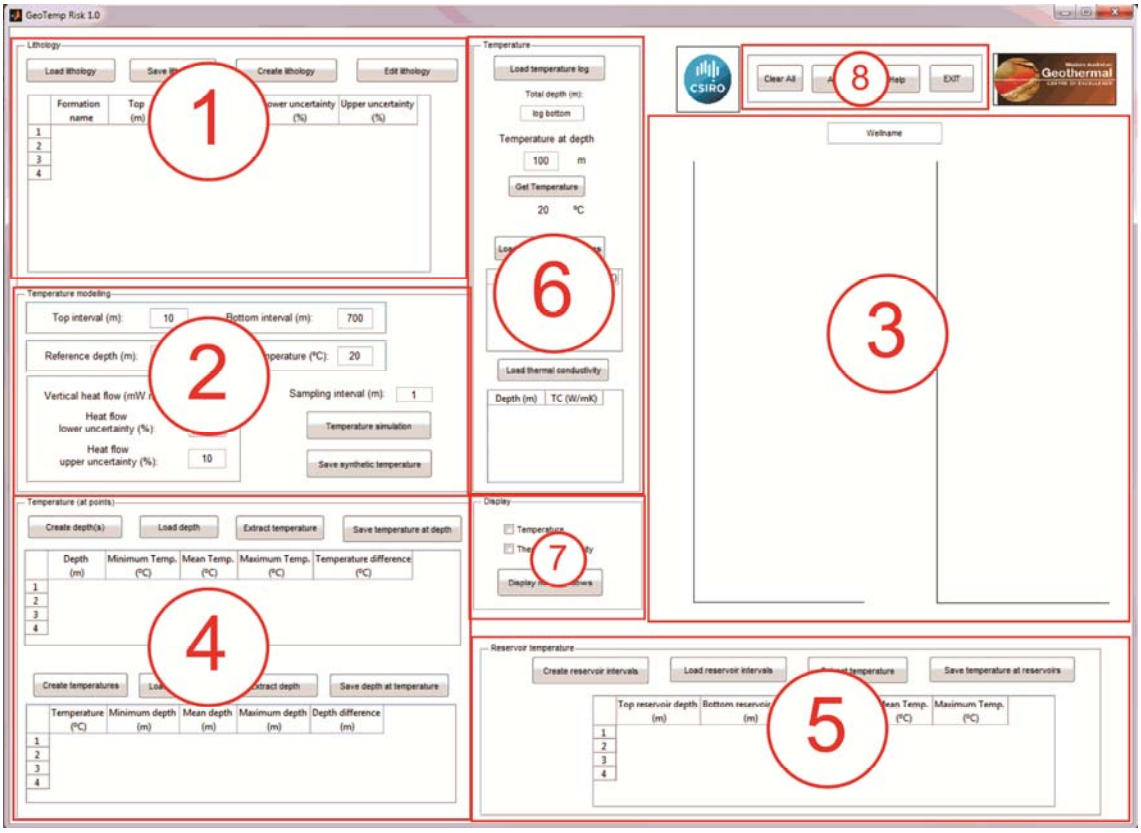


Figure 19: Screenshot showing the different panels of the 'GeoTemp Risk 1.0' interface.

Panel 1

A 'Load lithology' button enables the user to load the lithology sequence. The lithology data file format is described in details in section 8. The details of the lithology data are then displayed in the table under the button. The formation tops are then added to the graphs on the right.

The management of lithology is facilitated with the 'Save lithology', 'Create lithology' and 'Edit lithology' buttons. These buttons allow respectively saving, creating or editing a new lithology via the 'GeoTemp Lithology Management' module of the Wireline Workflow Toolbox component. The detailed description of these features is presented in section 6.1.

This panel presents the data in form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a deviation point.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).
- *Column 4* contains the lower formation thermal conductivity uncertainty (%).
- *Column 5* contains the upper formation thermal conductivity uncertainty (%).

Panel 2

The ‘Temperature simulation’ button computes a synthetic temperature log from the formation thermal conductivity, the lithology and the vertical heat flow value (Figure 20). The synthetic temperature log is displayed in the right graph of panel 3.

The ‘Save synthetic temperature’ button enables the user to export the synthetic temperature log in a file.

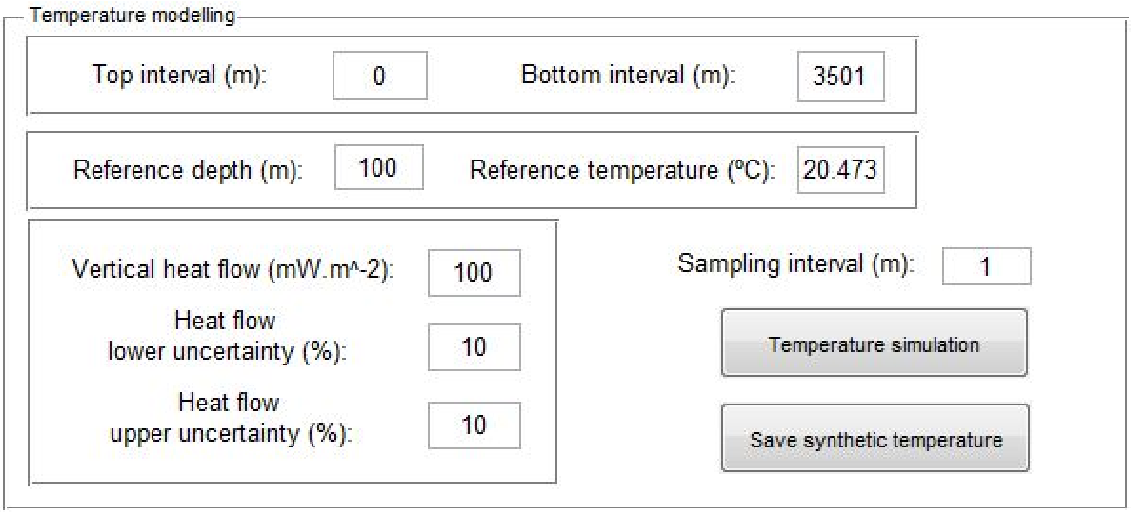


Figure 20: GeoTemp Risk, temperature modelling.

Panel 3

This panel displays the temperature and thermal conductivity versus depth as a result of interactions with Panel 1 and 2.

Panel 4

A ‘Create depth(s)’ button enables the user to add depth to the table.

A ‘Load depth’ button enables the user to load a file containing the depth values.

The ‘Extract temperature’ button computes the minimum, maximum and mean temperature at the depth. The temperature difference between minimum and maximum temperature is calculated. Results are displayed in the table below the button.

The ‘Save temperature at reservoirs’ button exports the depth with temperature data to a file as described in section 8.

This panel presents the data in form of a table where:
- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a reservoir.
- *Column 1* contains the depth (m).
- *Column 2* contains the lower temperature (°C).
- *Column 3* contains the arithmetic average temperature (°C).
- *Column 4* contains the upper temperature (°C).

- *Column 5* contains the temperature difference (°C).

A ‘Create temperature(s)’ button enables the user to add temperature value(s) to the table.

A ‘Load temperature’ button enables the user to load a file containing the temperature values.

The ‘Extract depth’ button computes the minimum, maximum and mean depth at the depth. The depth difference between minimum and maximum depth is calculated. Results are displayed in the table below the button.

The ‘Save temperature at reservoirs’ button exports the depth with temperature data to a file as described in section 8.

This panel presents the data in form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a reservoir.
- *Column 1* contains the depth (m).
- *Column 2* contains the lower temperature (°C).
- *Column 3* contains the arithmetic average temperature (°C).
- *Column 4* contains the upper temperature (°C).
- *Column 5* contains the temperature difference (°C).

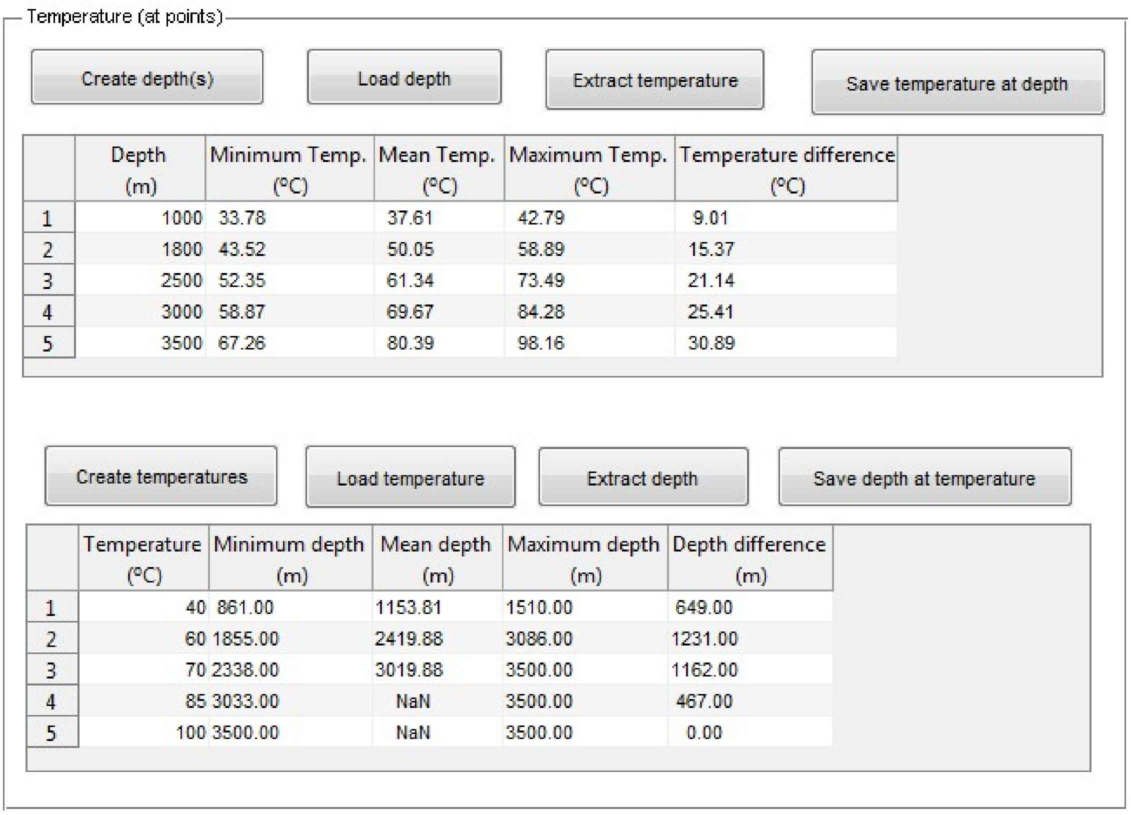


Figure 21: GeoTemp Risk, temperature extraction.

Panel 5

A ‘Create reservoir intervals’ button enables the user to create reservoirs by giving a top and bottom depth interval.

A ‘Load reservoir intervals’ button enables the user to load a file containing the reservoir depth interval.

The ‘Extract temperature’ button computes the temperature at top, bottom and reservoir average temperatures.

The ‘Save temperature at reservoirs’ button exports the reservoirs with temperature data to a file as described in section 8.

This panel presents the data in form of a table where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data for a reservoir.
- *Column 1* contains the top reservoir depth (m).
- *Column 2* contains the bottom reservoir depth (m).
- *Column 3* contains the minimum reservoir temperature (°C).
- *Column 4* contains the arithmetic average reservoir temperature (°C).
- *Column 5* contains the maximum reservoir temperature (°C).

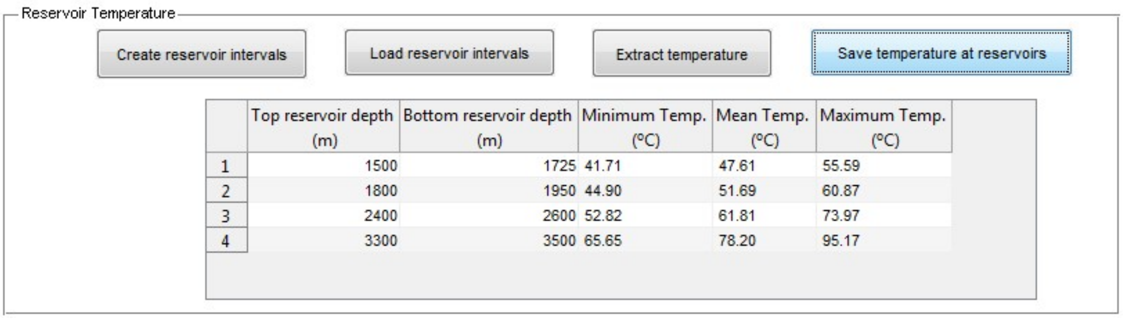


Figure 22: GeoTemp Risk, reservoir temperature.

Panel 6

A ‘Load temperature log’ button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the text ‘LAS file loaded’ appears at the right of the button and the ‘Name’ of the well appears at the right of the button. The total depth of the wireline measurements is presented on the right of the button. The temperature data are displayed in the graph on the right interface. The average sampling interval in Panel 3 is also updated.

A ‘Get temperature’ button allows the user to extract the temperature at a specific depth from the wireline temperature log (see panel 6 for loading wireline temperature log).

A ‘Load discrete temperatures’ button allows the user to load some discrete temperature data in the format described in section 8. The discrete temperature data (depth of measurement and value) appear in the table below the button.

A ‘Load discrete thermal conductivities’ button allows the user to load some discrete thermal conductivity data in the format described in section 8. The discrete thermal conductivity data (depth of measurement and value) appear in the table below the button.

Panel 7

This panel enables the user to open new windows with temperature versus depth and thermal conductivity versus depth graphs according to the activated checkbox.

6. WIRELINE WORKFLOW TOOLBOX

The ‘Wireline Workflow Toolbox’ offers extra features for the interpretation of wireline temperature measurements. These features are not part of the wireline workflow but enhance the interpretation capabilities with the possibility to create and modify lithologies, display several wireline temperature logs simultaneously, generate simple geographical temperature maps and to repeat some of the wireline workflow functionalities in batch mode for detailed analyses. Any of these modules are directly accessible from the ‘GeoTemp 1.0’ interface (Figure 2).

6.1 Lithology Management

The ‘Lithology Management’ module of the ‘Wireline Workflow Toolbox’ enables the user to create or edit a lithology and its associated properties such as the depth of its top contact, its temperature gradient, thermal conductivity and uncertainty, and its apparent vertical conduction error. Access to this module is available from the ‘GeoTemp 1.0’ interface but also from the ‘Data Evaluation’, ‘Conduction’, ‘Conduction Modelling’ and ‘Risk’ modules.

When launching this module from the main GeoTemp™ interface, the first interface (Figure 23) provides the user with the list of modules and the action to perform (create a new lithology or edit an existing one).

When launching this module from any of the modules of the GeoTemp™ Wireline Workflow, the ‘GeoTemp Lithology Management 1.0’ window appears (Figure 24). This interface is divided into three different panels.

- **Panel 1** presents the different buttons to load or save a lithology, add, remove or edit a formation.

- **Panel 2** refers to the lithology table.

Additionally, the window ‘GeoTemp Lithology Management 1.0’ offers another panel (Figure 24).

- **Panel 3** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

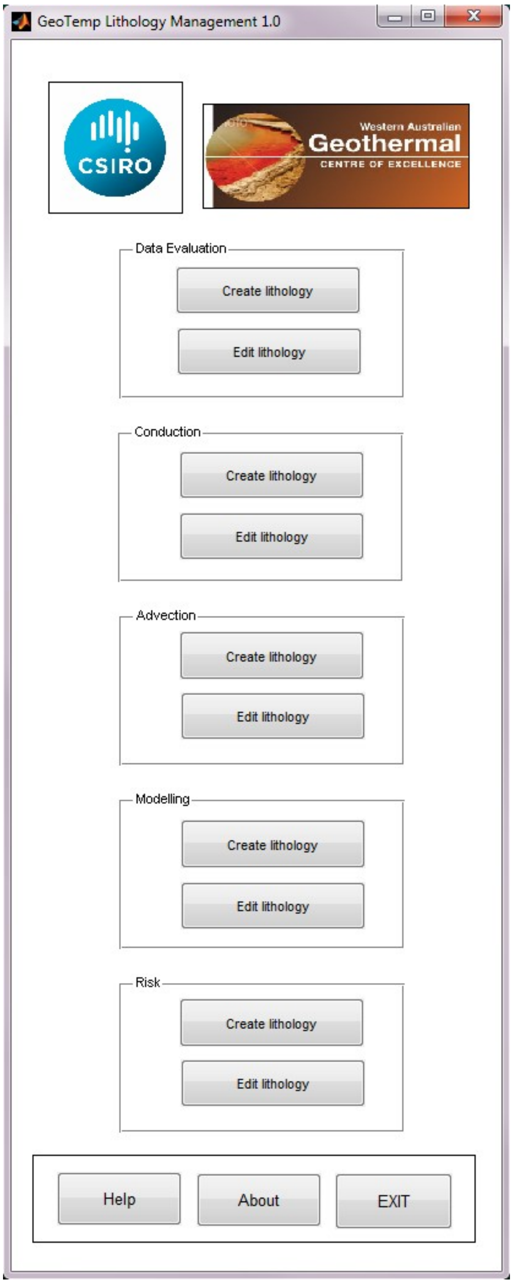


Figure 23: Screenshot of the Lithology management interface.

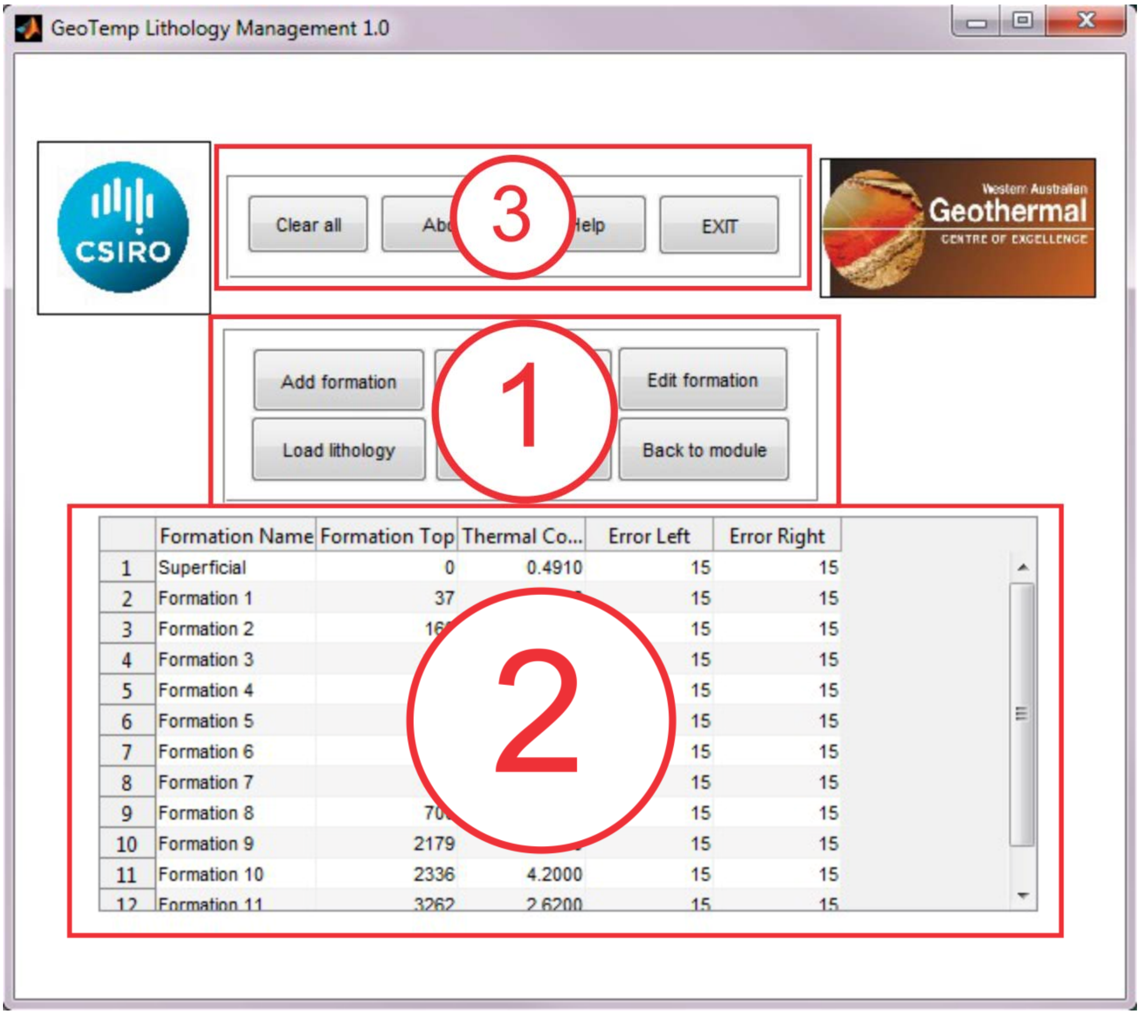


Figure 24: Screenshot showing the different panels of the 'GeoTemp Lithology Management 1.0' interface.

Technical details of the 'Lithology Management':

The main functions of this module are adding, removing and editing formations. For each module, different parameters are needed if the user wants to create a new formation.

Data evaluation: Formation name and formation top.

Conduction: Formation name, formation top, temperature gradient, temperature gradient error and known thermal conductivity.

Modelling: Formation name, formation top and thermal conductivity.

Risk: Formation name, formation top, thermal conductivity, lower error and upper error.

6.2 Viewer

The GeoTemp™ Viewer module allows the user to load and display several temperature profiles simultaneously to compare logs from different wells and measurements over time. To assist the interpretation, linear temperature versus depth lines can be loaded and displayed to set the limits of temperature logs. Graphical properties (e.g. graph title, legend, axis labels, horizontal and vertical axis ranges) can be edited by the user and displayed in the graphs. In addition, temperature at a given depth or a depth for a given temperature can be calculated and exported as a table.

When launching this module, by clicking the ‘GeoTemp Viewer’ button in the ‘GeoTemp 1.0’ main interface or from the GeoTemp Processing module, the ‘GeoTemp Viewer 1.0’ window appears (Figure 25).

This interface is divided into 7 different panels.

- **Panel 1** enables the loading of the wireline temperature measurements.

- **Panel 2** presents the interface between the temperature measurements database and the temperature measurements to be displayed.

- **Panel 3** refers to the graphics properties for displaying temperature measurements.

- **Panel 4** is the viewing panel for temperature data.

- **Panel 5** refers to the data analysis of the temperature measurements.

- **Panel 6** refers to the temperature and depth extraction from the temperature measurements.

Additionally, the window ‘GeoTemp Viewer 1.0’ offers another panel (Figure 25).

- **Panel 7** contains three buttons:
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

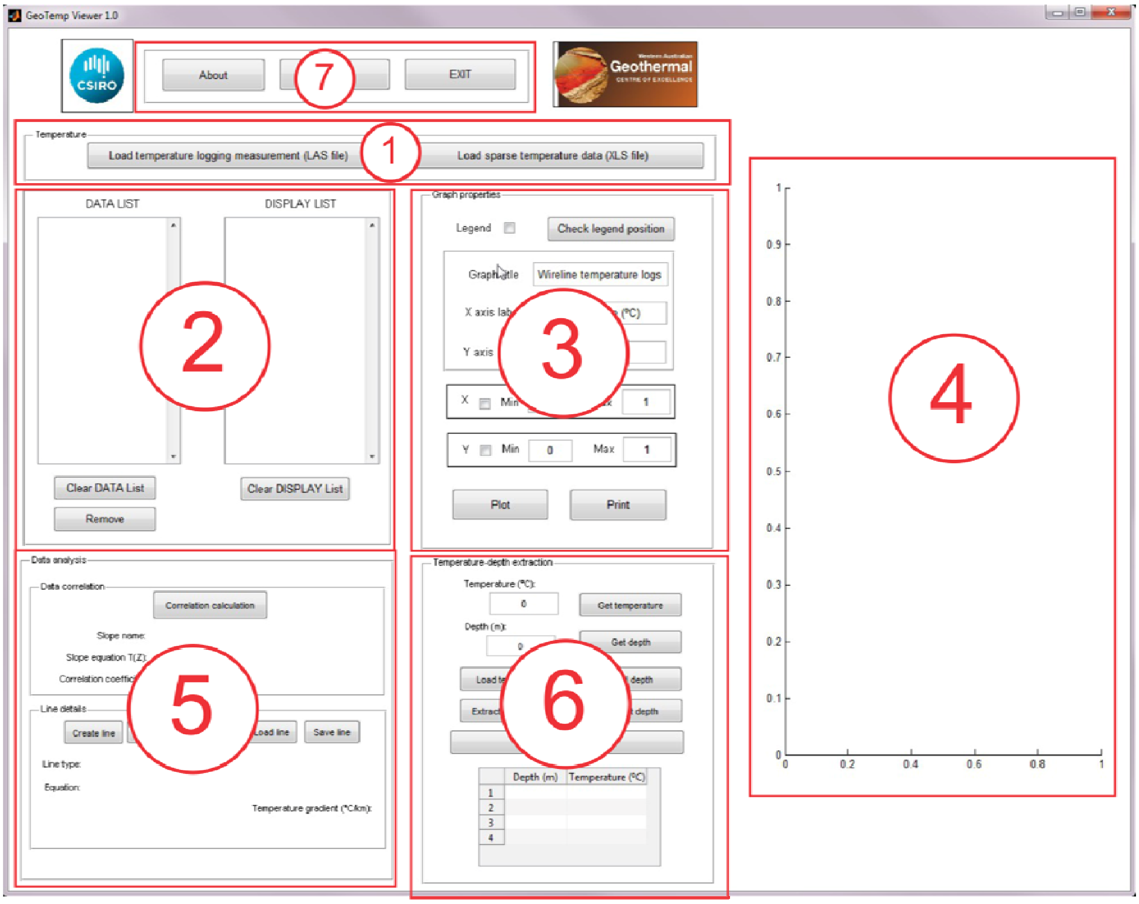


Figure 25: Screenshot showing the different panels of the ‘GeoTemp Viewer 1.0’ interface.

Panel 1

A ‘Load temperature logging measurement’ button allows the user to load the wireline temperature log. The GeoTemp LAS file loading process is described in details in section 8. Once performed, the name of the well appears in the left look-up table of Panel 2.

A ‘Load discrete temperature data’ button allows the user to load a discrete temperature data file. The GeoTemp XLS file loading process is described in details in section 8. Once performed, the name of the well appears in the left look-up table of Panel 2.

Panel 2

The ‘->’ (right arrow) button enables the transfer of the selected temperature dataset stored in the temperature database (left look-up table) to the display list (right look-up table).

The ‘<-‘ (left arrow) button removes the selected of the display list from the same list (right look-up table).

The ‘Clear DATA list’ removes all temperature dataset from the Temperature database look-up table.

The ‘Remove’ removes the selected temperature dataset from the Temperature database look-up table.

The ‘Clear DISPLAY list’ removes all temperature dataset from the Temperature database look-up table.

Panel 3

The ‘Plot’ button displays the temperature datasets in the Display list in the graphs of Panel 4. The graphics properties such as title and labels are added to this graph. If the checkboxes are activated, the range of temperature and depth are modified accordingly.

The ‘Print’ button displays the temperature datasets in the Display list in a new window. The graphic properties such as title and labels are added to this graph. If the checkboxes are activated, the range of temperature and depth are modified accordingly.

Panel 4

This panel displays the temperature versus depth wireline data as a result of interactions with Panel 2 and 3.

Panel 5

The ‘Correlation calculation’ button enables the user to calculate a linear interpretation or profile of the selected temperature measurement dataset in the DATA list. The details of the linear profile are presented below the button.

The ‘Create profile’ button enables the user to create a linear profile if two points or a point and the temperature gradient are known. There are two types of profiles: Envelope and normal. A profile type ‘envelope’ is displayed in red while a ‘normal’ profile is displayed in green.

The ‘Details’ button displays the equation of the profile below the button.

The ‘Edit’ button help the user to modify an existing profile.

The ‘Load profile’ button enables the user to load a line created previously.

The ‘Save profile’ button enables the user to save a profile into a file.

Panel 6

The ‘Get temperature’ button extracts the closest temperature values from the selected temperature measurements in the DATA list at the depth specified in the edit box on the left of the button.

The ‘Get depth’ button extracts the closest depth values from the selected temperature measurements in the DATA list at the temperature specified in the edit box on the left of the button.

The ‘Load temperature’ button loads a file containing a list of temperature data.

The ‘Load depth’ button loads a file containing a list of depth data.

The ‘Extract temperature’ button extracts the temperature data for the depth specified in the table of the panel.

The ‘Extract depth’ button extracts the depth data for the temperature specified in the table of the panel.

The ‘Save table’ button saves in a file the table on the bottom of the panel.

6.3 Regional Assessment

With the GeoTemp™ Regional Assessment module, a regional analysis of the temperature field by combination of single well analyses is made possible to provide regional temperature maps. The ‘Regional Assessment’ module allows the analysis of two-dimensional geographical temperature distributions. The analysis can only be carried out if at least three geo-referenced wireline temperature logs and a list of depths are available. In that case, the temperature at a given depth is extracted for each well. Each geo-referenced temperature is then used to generate an interpolated temperature map of the area delimited by the well coverage. Interpolation between different wells is carried out by using a Delaunay triangulation interpolation algorithm. Temperature maps at several depths can be computed simultaneously by entering several depths and can be either plotted in the interface or displayed separately. In addition, temperature at given geographical coordinates can be investigated using the temperature browser panel.

When launching this module from the 'GeoTemp 1.0' main interface, the 'GeoTemp Regional Assessment 1.0' window appears (Figure 26).

This interface is divided into 6 different panels.

- **Panel 1** enables the loading of the depths and well database.

- **Panel 2** refers to the extraction of the temperature estimates a the different depths and the display of those data.

- **Panel 3** refers to the computation and display of 2D temperature map at specified depths.

- **Panel 4** is the viewing panel for temperature data.

- **Panel 5** refers to the extraction of a temperature value at a given Easting/ Northing locations.

Additionally, the window 'GeoTemp Regional Assessment 1.0' offers another panel (Figure 26).

- **Panel 6** contains four buttons:
  - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
  - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
  - **About:** Gives the credit and contact details for further enquiries.
  - **Exit:** Closes the software.

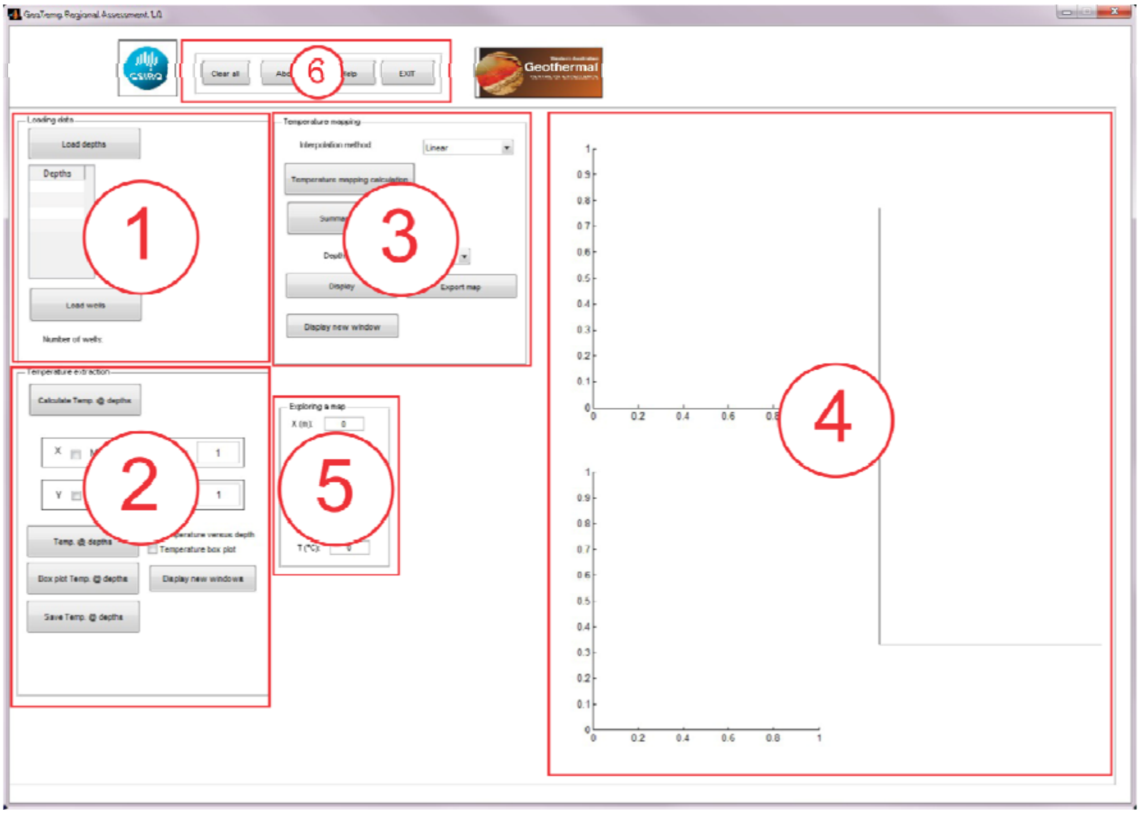


Figure 26: Screenshot showing the different panels of the 'GeoTemp Regional Assessment 1.0' interface.

Panel 1

A 'Load depths' button allows the user to load a list of depths. The input file loading process is described in details in section 8. Once performed, the different depth appears in the table below the button and the text 'Depth loaded'.

A 'Load well' button allows the user to load a list of temperature logs. The input file loading process is described in details in section 8. Once performed, the number of temperature logs appears below the button and the text 'Wells loaded' appears in the right of the button.

Panel 2

A 'Calculate temp. @ depths' button allows the user to compute for each temperature log the temperature at the depths loaded in Panel 1. Once performed, the text 'Temperature calculated' appears on the right of the button.

A 'Temperature @ depths' button displays the extracted temperature versus depth on the top left graphs of Panel 4.

A 'Box plotTemp. @ depths' button displays the extracted temperature versus depth in the form of a box plot on the bottom left graphs of Panel 4.

A 'Save Temp. @ depths' button enables the user to export the temperature at depth data. Once performed, the text 'Results saved' appears on the right of the button.

A 'Display new window' button opens a new window and plots the temperature versus depth and box plot temperature versus depth graphs according to the box checked.

Panel 3

A 'Temperature mapping' button computes the 2D interpolation of the temperature data for every depth specified in Panel 1. The algorithm selected in the look-up table above the button is used in this interpolation process.

The 'Summary plot' button opens a new window and displays all 2D temperature maps at the different depths presented in Panel 1.

The 'Display' button displays the 2D temperature map at the selected depth of the look-up table above the button into the right graph of Panel 4.

The 'Display new window' button opens a new window and displays the 2D temperature map at the selected depth of the look-up table above the button into it.

The 'Export map' button enables the user to export the 2D temperature map at the selected depth of the look-up table above the button into a file as described in section 8.

Panel 4

This panel displays the temperature versus depth and 2D temperature mapping results as result of the interaction with Panel 2 and 3.

Panel 5

The ‘Get Temperature’ button extracts the value of the temperature at the X and Y coordinates from the 2D temperature map previously generated at the depth selected in the look-up table above the button.

6.4 Guided Analysis

The ‘Wireline Guided Analysis’ module is a scriptable workflow that has been developed to assist the user in the automation of some tasks of the ‘Wireline Workflow’ module, allowing the user to focus on initial quality control and evaluation of critical parameters. For example, when calibrating several wireline temperature logs, an initial calibration test is carried out using the ‘Processing’ module before performing the calibration on the entire selection of wireline temperature logs. This module assists in the calculation of conductivity, heat flow, heat production, temperature calibration, temperature gradient and true vertical depth for several wells sequentially.

When launching this module, the ‘GeoTemp Guided Analysis 1.0’ window appears (Figure 27). This interface is divided in 4 different panels.

- **Panel 1** presents the Guided Analysis file management.

- **Panel 2** refers to the required additional data.

- **Panel 3** presents the well database and associated files.

Additionally, the window ‘GeoTemp Guided Analysis 1.0’ offers another panel (Figure 27).

- **Panel 4** contains four buttons:
    - **Clear all:** Re-initializes the variables and the graph to help the user to start a new dataset analysis.
    - **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
    - **About:** Gives the credit and contact details for further enquiries.
    - **Exit:** Closes the software.

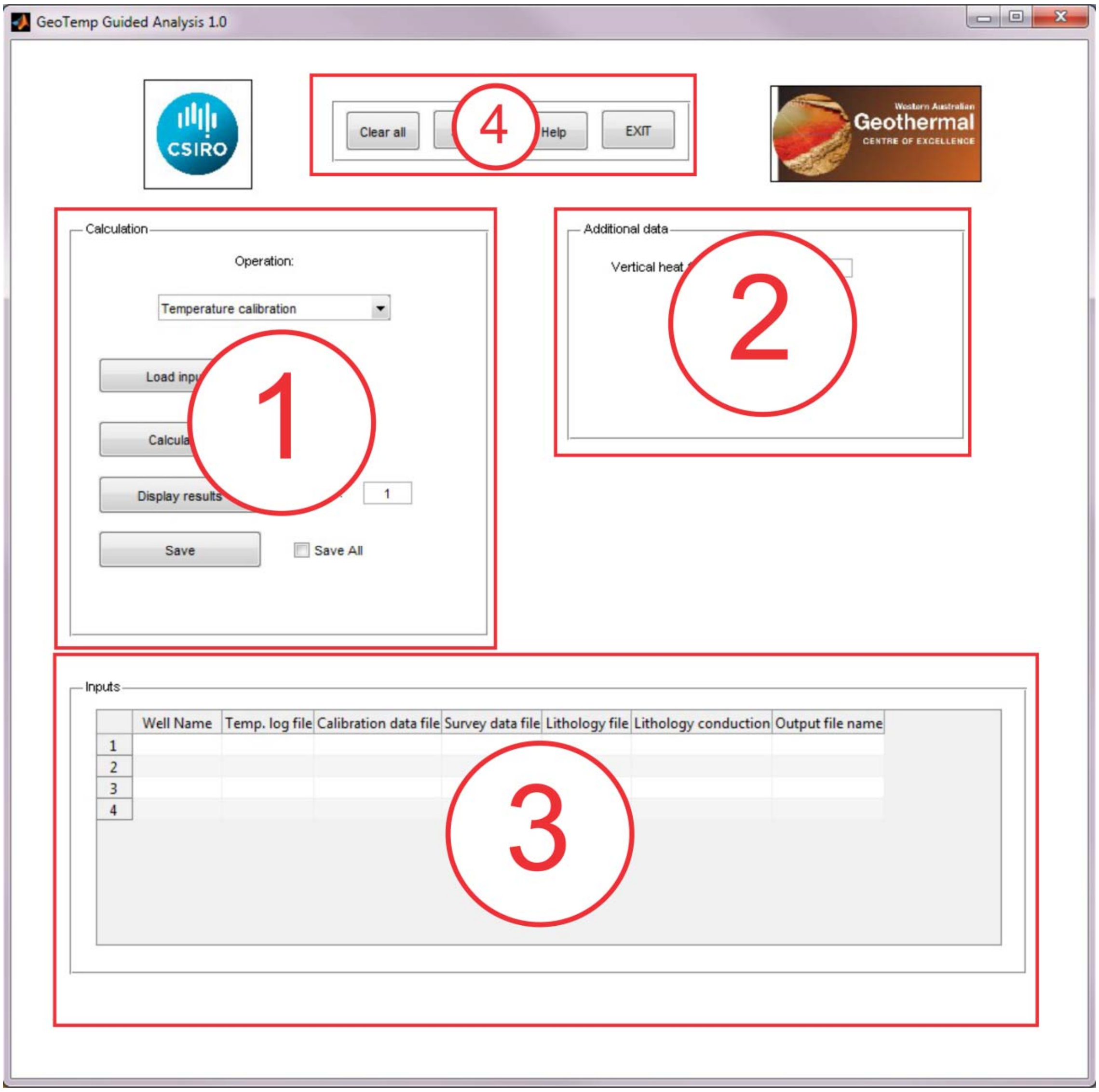


Figure 27: Screenshot showing the different panels of the 'GeoTemp Guided Analysis 1.0' interface.

Panel 1

The pop-up menu enables the user to select the type of operation to perform. The choice is limited to: Temperature calibration, TVD conversion, Heat production estimation, Temperature gradient estimation, Thermal conductivity and vertical heat flow.

A 'Load inputs' button allows the user to load a guided analysis well database. The input file loading process is described in details in section 8. Once loaded, the table of Panel 3 is populated with the information available in the well database.

The 'Calculation' button computes the operation required according to the pop-up menu selection.

The ‘Display results’ button shows the results for the well number specified on the right into a new window.

The ‘Save’ button enables the user to save the results according to the filename specified in the well database.

Panel 2

Panel 2 presents additional data for the Guided Analysis. When performing thermal conductivity inversion from a temperature profile, the Vertical heat flow value is required.

Panel 3

Panel 3 presents the file associated with each well for the interpretation.

7. DISCRETE TEMPERATURE VIEWER

The ‘Discrete Temperature Viewer’ is a stand-alone component which allows the user to proceed to a basin-scale assessment using discrete temperature data. This component allows the user to load, display and proceed to the simple interpretation of discrete temperature data. Several databases of discrete temperature data are publically available in Australia, e.g. PressurePlot (CSIRO 2007) or OzTemp (Holgate and Gerner 2010). These databases contain temperature information from several thousands of wells across Australia that can be classified by type of measurements (i.e. Bottom Hole Temperature (BHT), Repeated Formation Test (RFT), Drill Stem Test (DST)), and/or according to the degree of reliability of the dataset if available (e.g. PressurePlot).

From an exported portion of the database, the GeoTemp ‘Discrete Temperature Viewer’ module allows the user to display a part (e.g. by measurement type or degree of reliability) or the entire dataset, to view the data in a temperature versus depth plot and to investigate several linear correlations. By viewing the entire dataset, the user has the possibility to: (i) assess the quality of the data; (ii) investigate outliers and anomalies and; (iii) define upper and lower temperature limits to assess the overall temperature gradient variability.

When launching this module, by clicking the ‘Discrete Temperature Viewer’ button in the ‘GeoTemp 1.0’ main interface, the ‘GeoTemp Discrete Temperature Viewer 1.0’ window appears (Figure 28).

This interface is divided into 9 different panels.

- **Panel 1** enables the loading of the temperature measurements.
- **Panel 2** presents the interface between the temperature measurements database and the temperature measurements to be displayed.
- **Panel 3** refers to the graphic properties for displaying temperature measurements.
- **Panel 4** is the viewing panel for temperature data.
- **Panel 5** refers to the data analysis of the temperature measurements.
- **Panel 6** refers to the temperature and depth extraction from the temperature measurements.
- **Panel 7** refers to the temperature and depth extraction from the temperature measurements.
- **Panel 8** refers to the temperature and depth extraction from the temperature measurements.

Additionally, the window ‘GeoTemp Discrete Temperature Viewer 1.0’ offers another panel (Figure 25).

- **Panel 9** contains three buttons:

- **Help:** Opens the user manual (pdf file) where a description of the software and its use is provided.
- **About:** Gives the credit and contact details for further enquiries.
- **Exit:** Closes the software.

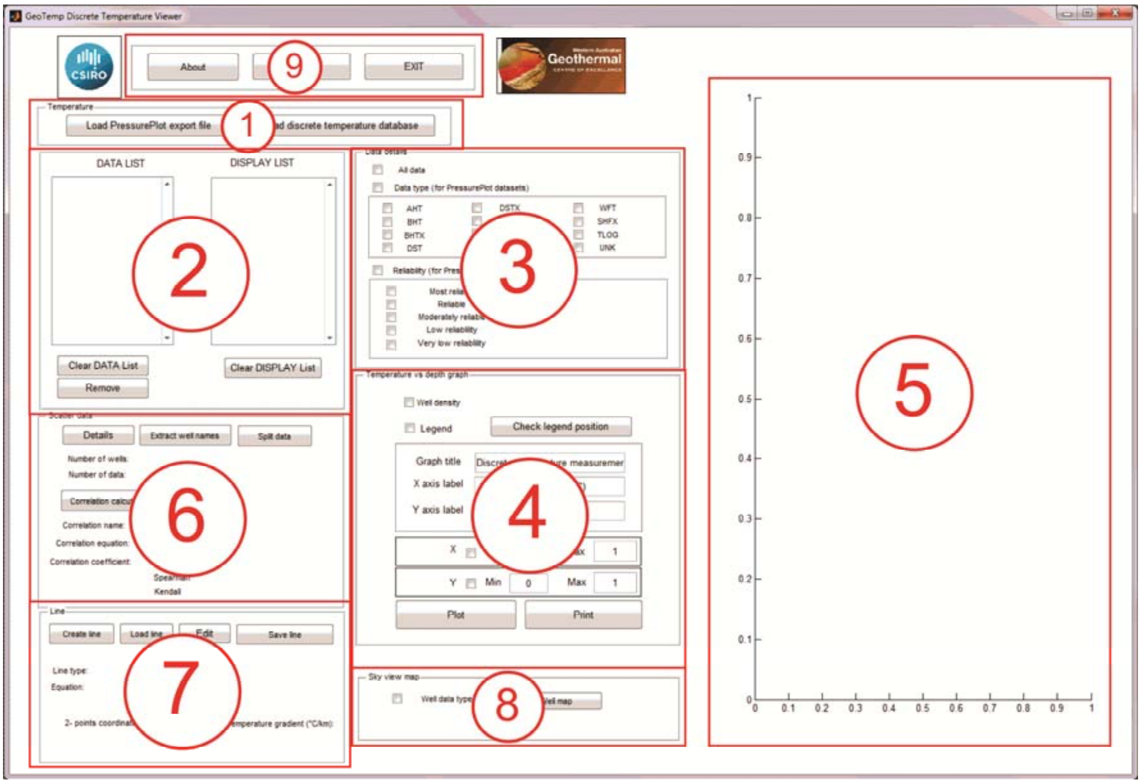


Figure 28: Screenshot showing the different panels of the 'GeoTemp Discrete Temperature Viewer 1.0' interface.

Panel 1

A 'Load PressurePlot export file' button allows the user to load a file containing temperature data exported by the PressurePlot software. The PressurePlot export file format is described in detail in section 8. Once performed, the name of the well appears in the left look-up table of Panel 2.

A 'Load discrete temperature database' button allows the user to load a file containing temperature data exported by the PressurePlot software. The PressurePlot export file format is described in details in section 8. Once performed, the name of the well appears in the left look-up tableof Panel 2.

Panel 2

The '->' (right arrow) button enables the transfer of the selected temperature dataset stored in the temperature database (left look-up table) to the display list (right look-up table).

The ‘<-‘ (left arrow) button removes the selected of the display list from the same list (right look-up table).

The ‘Clear DATA list’ removes all temperature dataset from the Temperature database look-up table.

The ‘Remove’ removes the selected temperature dataset from the Temperature database look-up table.

The ‘Clear DISPLAY list’ removes all temperature dataset from the Temperature database look-up table.

Panel 3

In this panel, the user selects the data to plot. The data can be displayed by measurement type and/or their associated reliability.

Panel 4

The ‘Plot’ button displays the temperature datasets in the Display list in the graphs of Panel 4. The graphic properties such as title and labels are added to this graph. If the checkboxes are activated, the range of temperature and depth are modified accordingly.

The ‘Print’ button displays the temperature datasets in the Display list in a new window. The graphic properties such as title and labels are added to this graph. If the checkboxes are activated, the range of temperature and depth are modified accordingly.

The ‘Legend’ checkbox allows the user to add a legend to the graph.

The ‘Well density’ checkbox allows adding a density distribution for the first temperature measurements.

The ‘X’ and ‘Y’ checkboxes enable to change the range of depth and temperature axes.

Panel 5

This panel displays the temperature versus depth wireline data as a result of interactions with Panel 2, 3 and 4.

Panel 6

The ‘Details’ button presents the number of wells and temperature measurements of the selected temperature dataset below the button and provides Panel 3 with the data availability information and reliability classification.

The ’Extract well names’ button opens a new window with a summary table with the temperature dataset analysed per well.

The ‘Split dataset’ button enables to split a temperature dataset into two datasets according to a given depth or temperature.

The ‘Correlation calculation’ button enables the user to calculate a linear interpretation of the selected temperature measurement dataset in the DATA list. The details of the linear curve are presented below the button.

Panel 7

The ‘Create profile’ button enables the user to create a linear profile if two points or a point and the temperature gradient are known. There are two types of profiles: envelope and normal. A profile type ‘envelope’ is displayed in red while a ‘normal’ profile is displayed in green.

The ‘Edit’ button helps the user to modify an existing profile.

The ‘Load profile’ button enables the user to load a profile created previously.

The ‘Save profile’ button enables the user to save a profile into a file.

Panel 8

The’ Well map’ button opens a new window with the location of the wells for the selected temperature dataset. If the ‘well data type’ checkbox is active then the colours of the wells are distributed according to the type of measurement available at the well.

<u>Technical details of GeoTemp Discrete Temperature Viewer:</u>

In PressurePlot, the temperature measurements are classified according to the acquisition process and their reliability. Details on the different acronyms used in the GeoTemp Discrete Temperature Viewer are given below.

<u>Data type:</u>

- AHT : Along Hole Temperature
- BHT : Bottom Hole Temperature
- BHTX : BHT Extrapolated Temperature

- DST : DST Temperature
- DSTX : DST Extrapolated Temperature
- FITP : FITP Temperature
- HPTX : Horner Plot Extrapolated Temperature
- MEAN : Mean Temperature
- WFT : WFT Temperature
- SHFX : Spherical Heat Flow Extrap Temperature
- TLOG : Temperature Log
- UNK : Unknown

<u>Reliability:</u>

- Most reliable
- Reliable
- Moderately reliable
- Low reliability
- Very low reliability

8. IMPORTING AND EXPORTING DATA

In this section, the different file formats used in GeoTemp™ are presented in detail. The different GeoTemp™ modules use different type of data as inputs and generate different types of outputs. Additionally, the procedure to export graphics and the loading/ saving of LAS files is also described.

8.1 Wireline temperature data

8.1.1 Loading wireline temperature logging data

The temperature log file should have an LAS version 2.0 file format. This format is defined by the Canadian Well Logging Society (http://www.cwls.org/las_info.php).

The Canadian Well Logging Society's Floppy Disk Committee has designed a standard format for log data on floppy disks. It is known as the LAS format (Log ASCII Standard). LASconsists of files written in ASCII (American Standard Code for Information Interchange) containing minimal header information and is intended for optical curves only. The purpose of the LAS format is to supply basic digital log data to users of personal computers in a format that is quick and easy to use. GeoTemp™ does not have a LAS version 2.0 reader. GeoTemp™ uses some parameters specified by the user to extract the relevant information from the LAS file.
In all GeoTemp modules, the process for loading LAS files is the same. When the user asks the software to load the LAS file, a window (Figure 29) appears. In this window, several parameters are required:

- *Name*, name of the well or the dataset (will be displayed in the interface and in the legend of graphics).
- *True Vertical Depth column*, Column number of the TVD data,
- *Gamma ray column*, Column number of the gamma ray data.
- *Temperature column*, Column number of the temperature data.
- *Not data*, Value disregarded as part of the dataset.
- *Nb Columns*, Number of column of the LAS file.
- *Nb lines header*, Number of lines of the header section.

Table 1: Wireline log default values

Field	Default value
Name	Name
TVD Column	1
Gamma-ray column	2
Temperature column	3
Not a data	-999.25
Nb Columns	5
Nb lines header	54

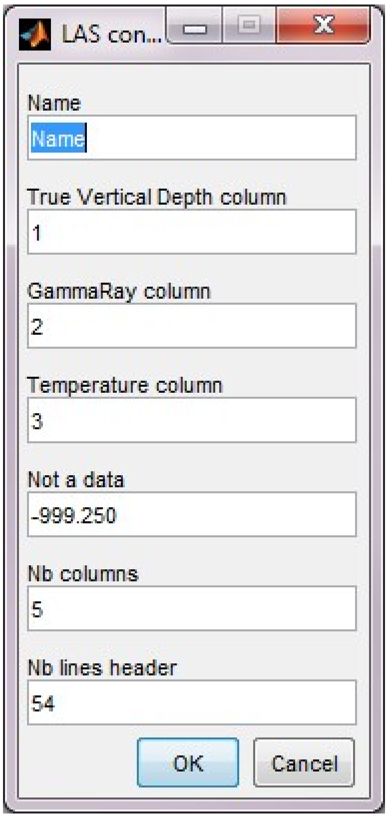


Figure 29: LAS file loading interface.

An example is illustrated in part of the 'MyWell2.las' file below.

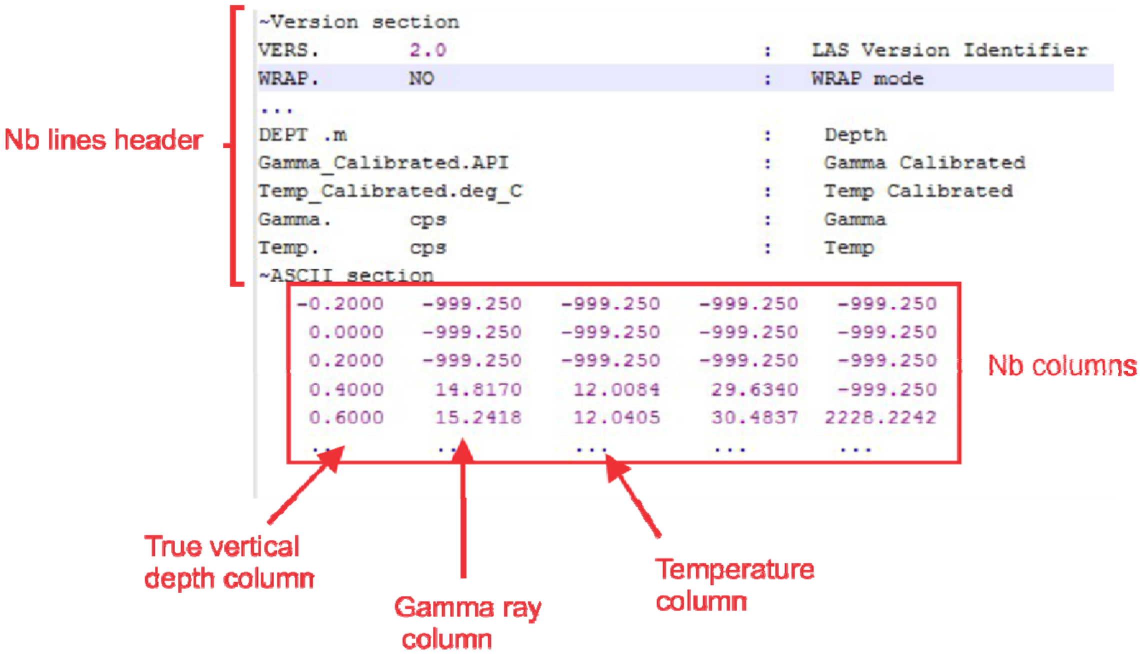


Figure 30: LAS file loading example.

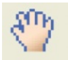
8.1.2 Saving wireline temperature logging data

Not yet available

8.2 Exporting graphics

When clicking the 'Display new window' or 'Export graphics' button, a new window (Referred to as 'Figure' window) is created to display the corresponding graph.

In the figure window, the plot can be:

- ✓ Zoomed in (using ) or zoomed out (using )
- ✓ Moved using 
- ✓ Rotated using 
- ✓ Printed using 
- ✓ Saved into various format (.fig, .jpeg, .ai, .eps etc) using  or 'File>Save As'.

In addition, the user can choose to modify and to export the plot by using 'File>Export setup'. In that case a new window appears (Figure 31) allowing the user to change the plot display and the saving parameters. User defined setup can be loaded and saved for further use. Once the user is satisfied with the figure display, the final figure can be saved into various formats including (.fig, .jpeg, .ai, or .eps by using the 'Export' button. This option allows the user to automatically obtain figures ready for publication.

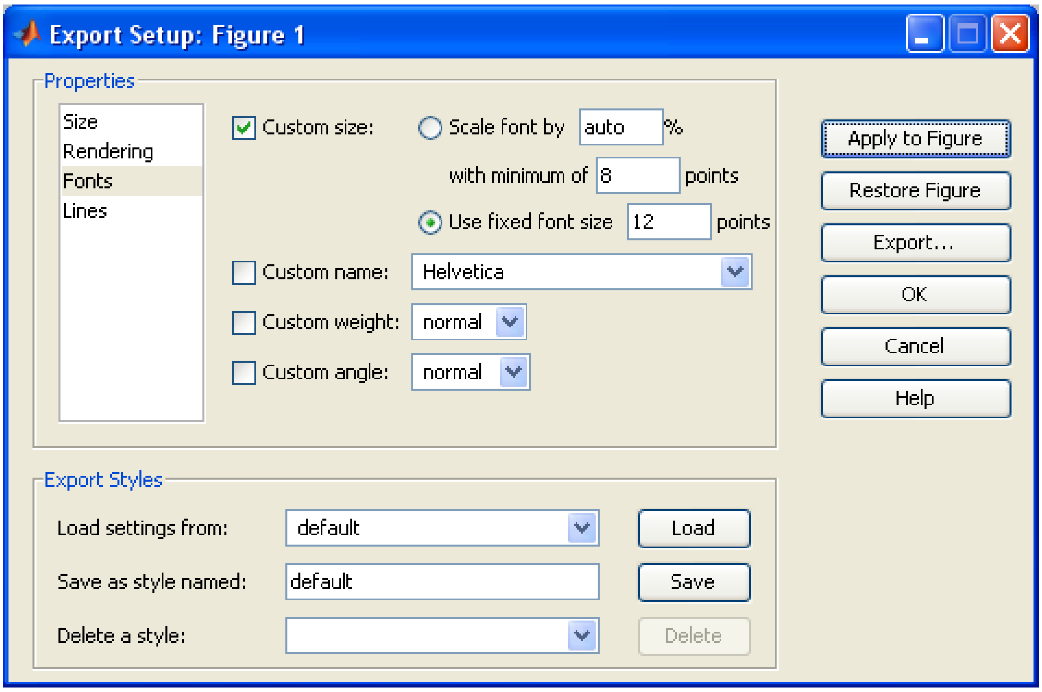


Figure 31: Screenshot showing the ‘Export Setup’ windows.

8.3 GeoTemp Processing

8.3.1 Temperature calibration input file

An example of the calibration input file required by GeoTemp Processing is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 2 where:

- The first line contains the header of each column describing which parameter is considered.
- Each row below the header contains the input data for a single calibration point.
- *Column 1* contains the calibration point in count per second (CPS).
- *Column 2* contains the calibration point in degree Celsius (°C).

An electronic example is available with example 1.

Table 2: GeoTemp Processing, calibration input file

CPS	Temperature (°C)
2212	10
2251	15
2267	17
...	...

8.3.2 Well survey input file

An example of the well survey input file required by GeoTemp Processing is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 3 where:

- The first line contains the header of each column describing which parameter is considered.
- Each row below the header contains the input data for a deviation point.
- *Column 1* contains the well name.
- *Column 2* contains the deviation depth (m).
- *Column 3* contains the azimuth angle (°).
- *Column 4* contains the dip angle (°).

An electronic example is available with example 1.

Table 3: GeoTemp Processing, well survey input file

HOLE-ID	DISTANCE	AZIMUTH	DIP
BM	0	60	-50
BM	200	60	-90
...	...	...	...

8.4 GeoTemp Heat Production

8.4.1 Lithology input file

An example of the lithology input file required by GeoTemp Heat Production and GeoTemp Data Evaluation is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 4 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).

An electronic example is available with example 2.

Table 4: GeoTemp Heat Production, lithology input file.

Formation Name	Formation Top
Superficial	0
Formation 1	37
Formation 2	166
...	...

8.4.2 Heat production output file

An example of the heat production output file exported by GeoTemp Heat Production and GeoTemp Data Evaluation is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 5 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the minimum heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 4* contains the maximum heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 5* contains the harmonic average heat production value of the formation ($\mu W\ m^{-3}$).
- *Column 6* contains the heat production standard deviation of the formation ($\mu W\ m^{-3}$).
- *Column 7* contains the cumulated vertical heat flow due to radiogenic heat production by formation ($\mu W\ m^{-2}$).

An electronic example is available with example 2.

Table 5: GeoTemp Heat Production output file

Formation Name	Formation top (m)	Minimum heat production (µW.m^-^3)	Maximum heat production (µW.m^-^3)	Average heat production (µW.m^-^3)	Standard deviation (µW.m^-^3)	Vertical heat flow (µW.m^-^2)
Superficial	0	0.10	0.42	0.21	0.05	7.68
Formation 1	37	0.09	0.61	0.21	0.08	25.59
…	…	…	…	…	…	…

8.5 GeoTemp Data Evaluation

8.5.1 Data Evaluation lithology output file

An example of the Data Evaluation lithology output file is presented in this section.

The data file is saved in the format described in Table 6 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the temperature gradient of the formation (°C km^{-1}).
- *Column 4* contains the temperature gradient calculation error for the formation.

- *Column 5* contains the temperature at top of the formation (°C)
- *Column 6* contains the arithmetic average temperature of the formation (°C).

An electronic example is available with example 3.

Table 6: GeoTemp Data Evaluation output file

Formation Name	Formation Top	Temperature Gradient	Error	Temperature at tops	Average temperature by formation
Superficial	0	0.20	3.11	12.01	16.19
Formation 1	37	0.02	0.17	19.46	20.52
Formation 2	166	0.04	0.16	21.77	24.84
...	...	...	...	...	...

8.5.2 Formation temperature gradient output file

An example of the formation temperature gradient output file is presented in this section.

The data file is saved in the format described in Table 7 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the depth of the estimate (m).
- *Column 2* contains the temperature gradient estimate (°C m^{-1})

An electronic example is available with example 3.

Table 7: Formation temperature gradient output file

True Vertical Depth (m)	Temperature Gradient (C m^{-1})
383	0.024
383.2	0.036
...	...

8.6 GeoTemp Conduction

8.6.1 Conduction lithology input file

An example of the lithology input file required by GeoTemp Conduction is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 8 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the temperature gradient of the formation (°C km^{-1}).
- *Column 4* contains the temperature gradient calculation error for the formation.
- *Column 5* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$) (this column is **OPTIONAL**)

An electronic example is available with example 3.

Table 8: GeoTemp Conduction lithology input file

Formation Name	Formation Top	Temperature Gradient	Temp. gradient error	Known Th. Cond.
Superficial	0	0.20	3.11	0
Formation 1	37	0.02	0.17	0
...	...	...	...	...

8.6.2 Conduction lithology output file

An example of the GeoTemp Conduction lithology output file is presented in this section. The data file is section. The data file is saved in the format described in

Table 9 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the temperature gradient of the formation (°C km^{-1}).
- *Column 4* contains the temperature gradient calculation error for the formation (%).
- *Column 5* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$)
- *Column 6* contains the formation interpreted vertical heat flow ($mW\ m^{-2}$).
- *Column 7* contains the known formation vertical heat flow ($mW\ m^{-2}$).
- *Column 8* contains the inverted formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).

An electronic example is available with example 3.

Table 9 : GeoTemp Conduction lithology output file

Formation Name	Formation Top	Temperature Gradient	Temp. gradient error	Known Th. Cond.	Interp.Qz	Known Qz	Interp. Th. Cond.
Superficial	0	0.20	3.11	0.00	0.00	0.05	0.27
Formation 1	37	0.02	0.17	0.00	0.00	0.05	3.02
...	...	...	...	...	...	...	...

8.6.3 Discrete thermal conductivity input file

An example of the thermal conductivity data input file required by GeoTemp Conduction, Conduction Modelling or Risk is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 10 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the depth (m).
- *Column 2* contains the thermal conductivity ($W\ m^{-1}\ C^{-1}$).

An electronic example is available with example 3.

Table 10: Discrete thermal conductivity data

Depth	Thermal conductivity
100	2
200	4
…	...

8.7 GeoTemp Conduction Modelling

8.7.1 Conduction Modelling lithology input file

An example of the lithology input file required by GeoTemp Conduction Modelling is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 11 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.

- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).

An electronic example is available with example 4.

Table 11: GeoTemp Conduction Modelling lithology input file

Formation Name	Formation Top	Thermal Conductivity
Superficial	0	0.49
Formation 1	37	5.59
...	...	...

8.7.2 Conduction Modelling lithology output file

An example of the lithology output file from GeoTemp Conduction Modelling is presented in this section. The data file is saved in the format described in Table 12 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).
- *Column 4* contains the temperature error (%).

An electronic example is available with example 4.

Table 12: GeoTemp Conduction Modelling lithology output file

Formation Name	Formation Top	Thermal Conductivity	Error (%)
Superficial	0	0.49	0
Formation 1	37	5.59	0
...	...	...	...

8.7.3 Discrete temperature input file

An example of the thermal conductivity data input file required by GeoTemp Conduction, Conduction Modelling or Risk is presented in this section.

In order to be loaded properly, the data file should be saved using the format described in Table 13 where:

- The first line contains the header of each column describing which parameter is considered in each row.

- Each row below the header contains the input data.
- *Column 1* contains the depth (m).
- *Column 2* contains the temperature (°C).

An electronic example is available with example 4.

Table 13: Discrete temperature data

Depth (m)	Temperature (°C)
100	20
200	40
…	...

8.7.4 Conduction Modelling temperature output file

An example of the GeoTemp Conduction Modelling temperature log output file is presented in this section. The data file is saved in the format described in Table 14 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the depth (m).
- *Column 2* contains the temperature (°C).

An electronic example is available with example 4.

Table 14: GeoTemp Conduction Modelling temperature output file

Depth (m)	Synthetic temperature (°C)
0	20
1	20.03
2	20.06
…	…

8.7.5 Conduction Modelling/ Risk reservoir interval input file

An example of the reservoir interval input file required by GeoTemp Conduction Modelling is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 15 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.

- *Column 1* contains the top reservoir depth (m).
- *Column 2* contains the bottom reservoir depth (m).

An electronic example is available with example 4.

Table 15: GeoTemp Conduction Modelling reservoir interval input

Top reservoir depth (m)	Bottom reservoir depth (m)
1500	1725
...	...

8.7.6 Conduction Modelling reservoir interval output file

An example of the GeoTemp Conduction Modelling temperature log output file is presented in this section. The data file is saved in the format described in Table 16 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the top reservoir depth (m).
- *Column 2* contains the bottom reservoir depth (m).
- *Column 3* contains the minimum reservoir temperature (°C).
- *Column 4* contains the arithmetic average reservoir temperature (°C).
- *Column 5* contains the maximum reservoir temperature (°C).

An electronic example is available with example 4.

Table 16: GeoTemp Conduction Modelling reservoir interval output

Top reservoir depth (m)	Bottom reservoir depth (m)	Min. temperature (°C)	Mean temperature (°C)	Max. temperature (°C)
1500	1725	56.74	61.74	59.24
1800	1950	63.40	66.74	65.07
...	...	...	...	...

8.8 GeoTemp Risk

8.8.1 Risk lithology input file

An example of the lithology input file required by GeoTemp Risk is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 17 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the formation name.
- *Column 2* contains the formation top (m).
- *Column 3* contains the formation thermal conductivity ($W\ m^{-1}\ C^{-1}$).
- *Column 4* contains the lower formation thermal conductivity uncertainty (%).
- *Column 5* contains the upper formation thermal conductivity uncertainty (%).

An electronic example is available with example 5.

Table 17: GeoTemp Risk lithology input file

Formation Name	Formation top (m)	Thermal conductivity	Lower uncertainty	Upper uncertainty
Superficial	0.00	0.49	15.00	15.00
Formation 1	37.00	5.59	15.00	15.00
...	...	...	...	...

8.8.2 Risk temperature output file

An example of the GeoTemp Risk temperature log output file is presented in this section. The data file is saved in the format described in Table 18 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the depth (m).
- *Column 2* contains the temperature (°C).
- *Column 3* contains the lower temperature envelope (°C).
- *Column 4* contains the upper temperature envelope (°C).

An electronic example is available with example 5.

Table 18: GeoTemp Risk temperature output file

Depth (m)	Synthetic temperature (°C)	Lower envelope (°C)	Upper envelope (°C)
0.00	13.94	15.25	12.15
1.00	14.08	15.37	12.34
2.00	14.22	15.48	12.52
...	...	...	...

8.8.3 Risk reservoir interval output file

An example of the GeoTemp Conduction Modelling temperature log output file is presented in this section. The data file is saved in the format described in Table 19 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the top reservoir depth (m).
- *Column 2* contains the bottom reservoir depth (m).
- *Column 3* contains the minimum reservoir temperature (°C).
- *Column 4* contains the Arithmetic average reservoir temperature (°C).
- *Column 5* contains the maximum reservoir temperature (°C).

An electronic example is available with example 5.

Table 19: GeoTemp Risk reservoir interval output

Top Reservoir Depth (m)	Bottom reservoir Depth (m)	Min. temperature (°C)	Mean temperature (°C)	Max. temperature (°C)
1500.00	1725.00	41.24	47.14	55.12
1800.00	1950.00	44.43	51.22	60.40
...	...	...	...	...

8.8.4 Risk temperature depth input file

An example of the temperature depth input file required by GeoTemp Risk is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 20 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the temperature (°C).

Table 20: GeoTemp Risk temperature depth input

Temperature (°C)
40
60
...

An electronic example is available with example 5.

Risk temperature depth output file

An example of the GeoTemp Risk temperature depth output file is presented in this section. The data file is saved in the format described in Table 21 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the temperature (°C).
- *Column 2* contains the lower depth (m).
- *Column 3* contains the arithmetic average depth (m).
- *Column 4* contains the upper depth (m).
- *Column 5* contains the depth difference (m).

An electronic example is available with example 5.

Table 21: GeoTemp Risk temperature depth output

Temperature (°C)	Min. depth (m)	Mean depth (m)	Max. depth (m)	Diff. depth (m)
40.00	662.00	746.81	844.00	182.00
60.00	1485.00	1646.81	1844.00	359.00
70.00	1894.00	2096.81	2331.00	437.00

8.8.5 Risk depth temperature input file

An example of the depth temperature input file required by GeoTemp Risk is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 22 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the depth (m).

Table 22: GeoTemp Risk depth temperature input

Depth (m)
1000
1800
2500

An electronic example is available with example 5.

8.8.6 Risk depth temperature output file

An example of the GeoTemp Risk depth temperature output file is presented in this section. The data file is saved in the format described in Table 23 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the depth (m).
- *Column 2* contains the lower temperature (°C).
- *Column 3* contains the arithmetic average temperature (°C).
- *Column 4* contains the upper temperature (°C).
- *Column 5* contains the temperature difference (°C).

An electronic example is available with example 5.

Table 23: GeoTemp Risk depth temperature output

Depth (m)	Min. Temperature (°C)	Mean Temperature (°C)	Max. Temperature (°C)	Diff. Temperature (°C)
1000.00	40.16	45.63	53.02	12.87
1800.00	54.07	63.40	76.03	21.96
2500.00	66.69	79.52	96.89	30.20

8.9 GeoTemp Viewer

8.9.1 Viewer line input/ output file

An example of the depth input file required by GeoTemp Viewer is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 24 where:

- The first line contains the header of each column describing which parameter is considered in the following row.
- *Column 1* contains the temperature (m).
- *Column 2* contains the depth (m).
- *Line 2 Column 3* contains the envelope logical. When set to 0, the line is not an envelope. When set to 1, the line is an envelope.
- *Line 2 Column 4* contains the slope logical. When set to 0, the line is not a slope. When set to 1, the line is a slope.
- *Line 2 Column 5* contains the correlation coefficient if the line is a slope.
- *Line 2 Column 6* contains the temperature gradient.
- *Line 2 Column 7* contains the depth of the first point.
- *Line 2 Column 8* contains the temperature of the first point.
- *Line 2 Column 9* contains the depth of the second point.
- *Line 2 Column 10* contains the temperature of the second point.

Table 24: GeoTemp Regional Assessment depth input

T (°C)	Z (m)	Envelope	Slope	Correlation coef	Temperature gradient (°C/m)	Z1	T1	Z2	T2
19.2	100	0	1	0.990292101	0.037967599	0	15.45066		
24.9	250								
…	…								

8.9.2 Viewer depth input file

An example of the depth temperature input file required by GeoTemp Viewer is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 25 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the depth (m).

Table 25: GeoTemp Viewer depth input

Depth (m)
100
180
...

8.9.3 Viewer temperature input file

An example of the temperature depth input file required by GeoTemp Viewer is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 26 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the temperature (°C).

Table 26: GeoTemp Viewer temperature input

Temperature (°C)
25
50
...

8.9.4 Viewer temperature depth output file

An example of the GeoTemp Risk depth temperature output file is presented in this section. The data file is saved in the format described in Table 27 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the depth (m).
- *Column 2* contains the temperature (°C).

Table 27: GeoTemp Viewer depth temperature output

Depth (m)	Temperature (°C)
100	20
200	22.66667
...	...

8.10 GeoTemp Regional Assessment

8.10.1 Regional Assessment depth input file

An example of the depth input file required by GeoTemp Regional Assessment is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 28 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the depth (m).

Table 28: GeoTemp Regional Assessment depth input

Depth (m)
100
150
...

8.10.2 Regional Assessment well database input file

An example of the well database input file required by GeoTemp Regional Assessment is presented in this section. In order to be loaded properly, the data file should be saved using the format described in Table 29 where:

- The first line contains the header of each column describing which parameter is considered in each row.

- Each row below the header contains the input data.
- *Column 1* contains the Well name.
- *Column 2* contains the temperature log file name.
- *Column 3* contains the Easting (m) of the well.
- *Column 4* contains the Northing (m) of the well.
- *Column 5* contains the ground level at the well location (m).
- *Column 6* contains the number of the true vertical depth column.
- *Column 7* contains the number of the gamma ray column.
- *Column 8* contains the number of the temperature column.
- *Column 9* contains the not a number value.
- *Column 10* contains the number of columns of the log file.
- *Column 11* contains the header number of lines of the log file.

Table 29: GeoTemp Regional Assessment well database input

Wellname	**Log file**	**X**	**Y**	**GL**	**TVDColumn**	**GRColumn**	**TempColumn**	**NANValue**	**Columns**	**Lines**
AM2	AM2.las	365659	6529664	36	1	2	2	-999.25	2	36
AM3	AM2.las	367230	6535516	27	1	2	2	-999.25	2	36
…	…	…	…	…	…	…	…	…	…	…

8.10.3 Regional Assessment temperature output file

An example of the temperature output file from GeoTemp Regional Assessment is presented in this section. The data file is saved using the format described in Table 30 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the Well name.
- *Column 2* contains the Easting (m) of the well.
- *Column 3* contains the Northing (m) of the well.
- *Column 4* contains the temperature at the first depth for this well.
- *Column 5* contains the temperature at the second depth for this well.

The additional column contains the temperature at increasing depths.

Table 30 : GeoTemp Regional Assessment temperature output file

Well Name	X Location	Y Location	Temperature @Z1	Temperature @Z2	…
AM2	365659	6529664	23.6686	25.8647	…
AM3	367230	6535516	22.7108	24.2071	…
…	…	…	…	…	…

8.10.4 Regional Assessment temperature map output file

An example of the temperature map output file from GeoTemp Regional Assessment is presented in this section. The data file is saved using the format described in Table 31 where:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the output data.
- *Column 1* contains the Easting (m).
- *Column 2* contains the Northing (m).
- *Column 3* contains the depth (mAHD).
- *Column 4* contains the temperature at the second depth for this well.

Table 31 : GeoTemp Regional Assessment temperature map output file

365659.000000	6398413.000000	100.000000	23.9
365659.000000	6399098.515000	100.000000	24.1
...	...	...	...

8.11 GeoTemp Guided Analysis

8.11.1 Guided Analysis input file

An example of the well database input file required by GeoTemp Guided Analysis is presented in this section. In order to be loaded properly, the data file should be saved using the format described below

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the Well name.
- *Column 2* contains the temperature log file name.
- *Column 3* contains the temperature calibration file name (if none, leave empty).
- *Column 4* contains the well survey file name (if none, leave empty).
- *Column 5* contains the lithology file name (if none, leave empty).
- *Column 6* contains the conduction lithology file name (if none, leave empty).
- *Column 7* contains the output file name.
- *Column 8* contains the number of the true vertical depth column.
- *Column 9* contains the number of the gamma ray column.
- *Column 10* contains the number of the temperature column.
- *Column 11* contains the number of the temperature CPS column.
- *Column 12* contains the not a number value.
- *Column 13* contains the number of columns of the log file.
- *Column 14* contains the header number of lines of the log file.

8.12 GeoTemp Discrete Temperature viewer

8.12.1 Discrete Temperature Viewer input file

An example of the PressurePlot input file for the GeoTemp Discrete Temperature Viewer is presented in this section. The data file is organized with 37 columns. However, not every column is useful for GeoTemp Discrete Temperature Viewer. The format is described:

- The first line contains the header of each column describing which parameter is considered in each row.
- Each row below the header contains the input data.
- *Column 1* contains the type of data, default for GeoTemp is Temperature.
- *Column 2* contains the well ID.
- *Column 3* contains the well name.
- *Column 4* contains the total true vertical depth (m).
- *Column 5* contains the total measured depth (m).
- *Column 6* contains the temperature (°C).
- *Column 13* contains the PressurePlot internal quality code for the temperature measurement.
- *Column 22* contains the source of the temperature measurement.
- *Column 31* contains the longitude coordinates of the well.
- *Column 32* contains the latitude coordinates of the well.
- *Column 33* contains the datum elevation (m).
- *Column 34* contains the spud date.

9. EXAMPLES

The following example s describe the steps required to perform some analyses of the temperature measurements with the GeoTemp software.

9.1 Example 1: Processing of a wireline temperature log

In this example, we will calibrate, convert the depth and assess the quality of a wireline temperature log.

The different files (Table 32) for the wireline temperature processing example are located in the ‘Tutorials\WirelineWorkflow\0_Processing\’ folder.

The data calibration is the first feature of the GeoTemp Processing module. Load the uncalibrated temperature log and the calibration dataset to calibrate the temperature log. The results of the calibration should correspond to Figure 32. Once performed, proceed with the TVD conversion and then the reference datum correction and the assessment of the wireline log. For this dataset, the ground level is 13 mAHD.

The different steps to follow for the loading of the data and the calculations are described in the GeoTemp Processing section and are not repeated here. Once the data have been loaded and the parameters entered, the ‘GeoTemp Processing 1.0’ window should be similar to the one given below (Figure 32).

Table 32: List of input files for the ‘GeoTemp Processing’ example

Function	Filename
Uncalibrated temperature log	MyWell2_Uncalibrated.las
Calibrated temperature log	MyWell2.las
Calibration dataset	CalibrationData_Processing.xls
Survey data	MyWell_SurveyData.xls

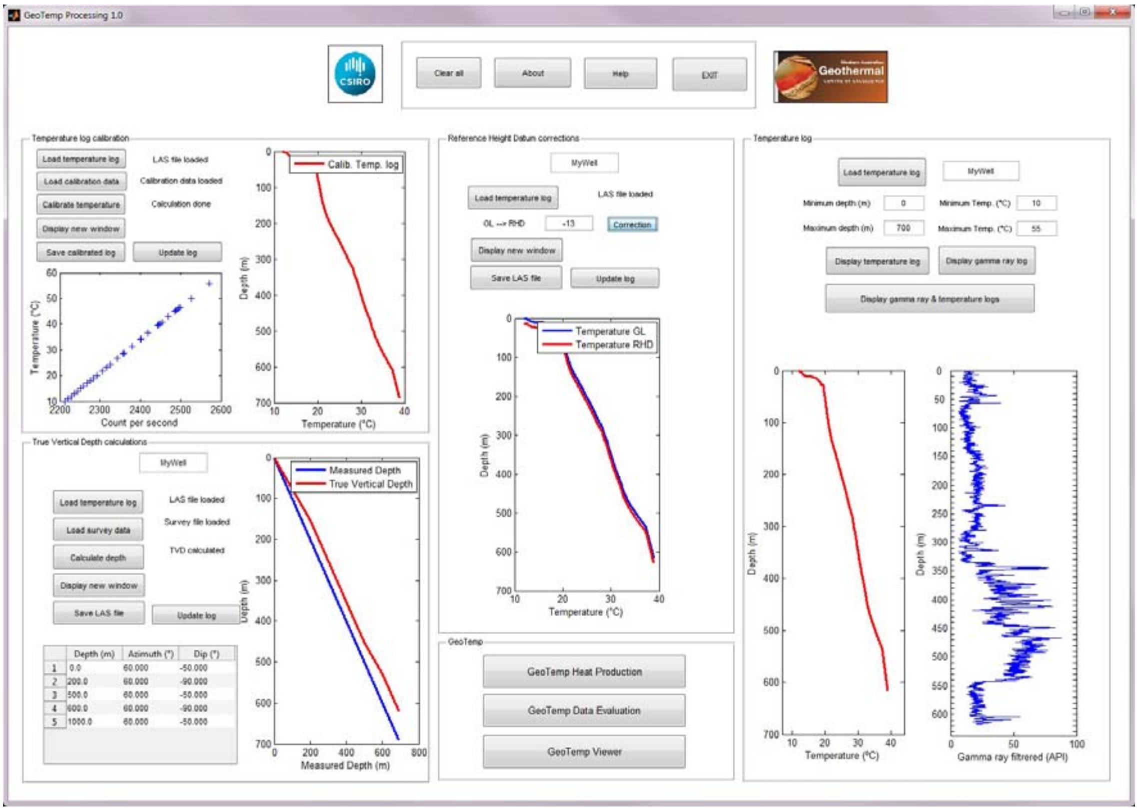


Figure 32: Example 1 results.

9.2 Example 2: Heat production estimation

In this example, we calculate the heat production rate per formation and for the entire well interval using the gamma ray measurements and the lithology information.

The different files (Table 33) for this example are located in the 'Tutorials\WirelineWorkflow\1_HeatProduction\' folder.

Table 33: List of files for the 'GeoTemp Heat Production' example

Function	Filename
Wireline gamma-ray log	MyWell2.las
Lithology	MyWell_Lithology.xls

The different steps to follow for loading of the data and the calculations are described in the GeoTemp Heat Production section and are not repeated here. Once the data have been loaded and the parameters entered, the 'GeoTemp Processing 1.0' window should be similar to the one given below (Figure 33). The heat production results per formation are also available in the 'MyWell_HeatProduction.xls' file in the same folder.

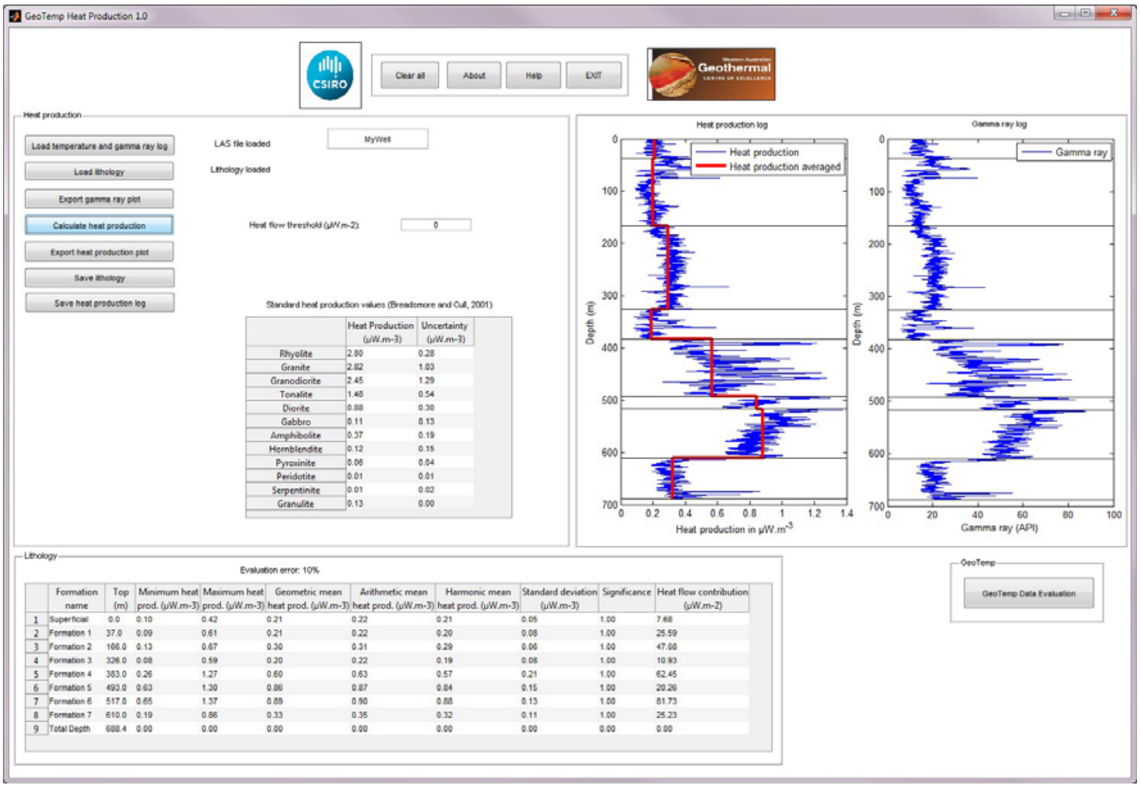


Figure 33: Example 2 results.

9.3 Example 3: Evaluation of apparent vertical heat conduction

In this example, we evaluate the wireline temperature measurements regarding the apparent vertical heat conduction regime using the gamma ray and temperature measurements and the lithology information.

The different files (Table 34) for this example are located in the 'Tutorials\WirelineWorkflow\2_DataEvaluation\' folder.

Table 34: List of files for the 'GeoTemp Data Evaluation' example

Function	Filename
Wireline temperature log	MyWell2.las
Lithology	MyWell_Lithology.xls

The different steps to follow for the loading of the data and the calculations are described in the GeoTemp Data Evaluation section and are not repeated here. Once the data have been loaded and the parameters entered, the 'GeoTemp Data Evaluation 1.0' window should be similar to the one given below (Figure 34). The temperature gradient results per formation are also available in the 'MyWell_DataEvaluationOutput.xls' file in the same folder. The detailed temperature gradients of 'Formation 4' are available in the 'Formation4_TGhistogram.xls' file.

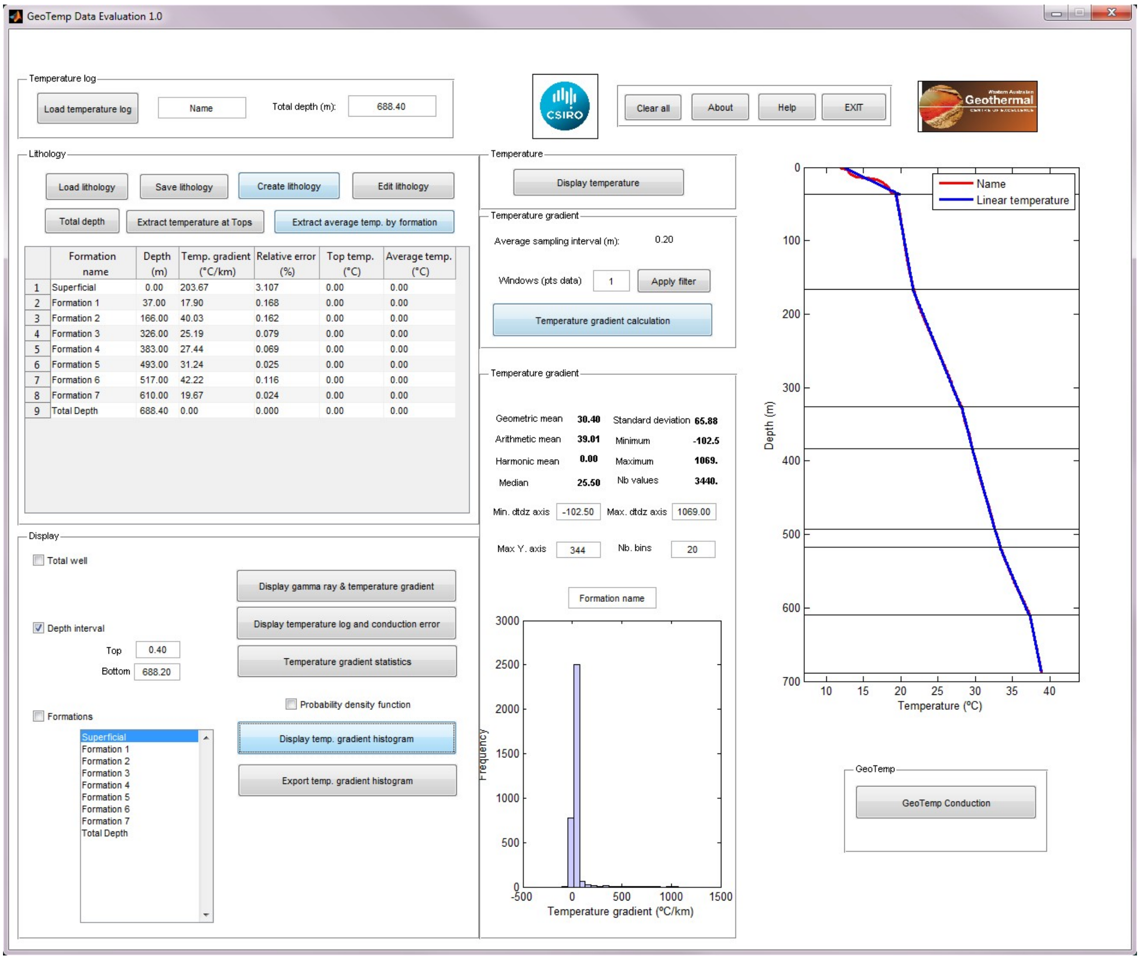


Figure 34: Example 3 results.

9.4 Example 4: Vertical conduction characterization

In this example, we characterize the parameters associated with an apparent vertical heat conduction regime.

The different files (Table 35) for this example are located in the 'Tutorials\WirelineWorkflow\3_Conduction\' folder.

Table 35: List of files for the 'GeoTemp Conduction' example

Function	Filename
Wireline temperature log	MyWell2.las
Lithology	MyWell_LithologyConduction.xls
BHT measurements	MyWell_BHTData.xls
Thermal conductivity measurements	MyWell_ThermalConductivityData.xls

The different steps to follow for loading of the data and the calculations are described in the GeoTemp Conduction section and are not repeated here. Once the data have been loaded and the parameters entered, the 'GeoTemp Conduction 1.0' window should be similar to the one given below (Figure 35). The thermal conductivity inverted estimates per formation are also available in the 'MyWell_LithologyConductionOutput.xls' file in the same folder.

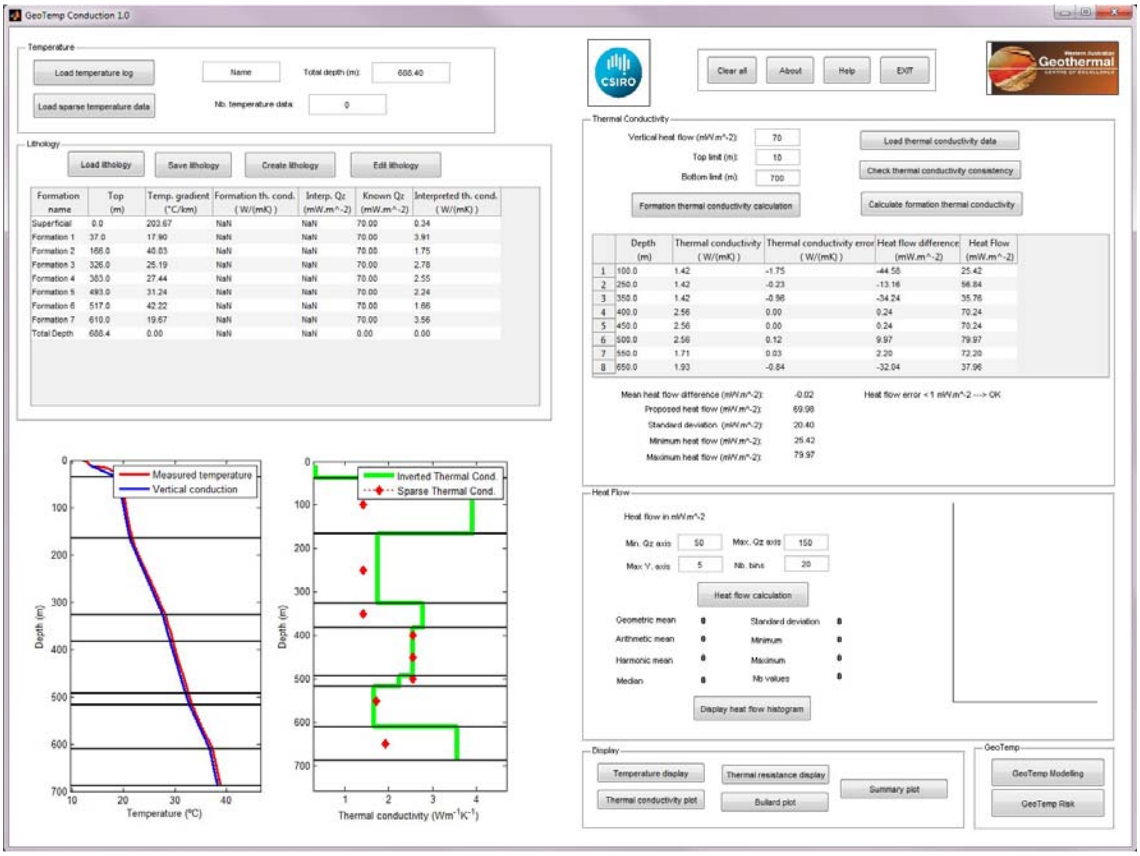


Figure 35: Example 4 results.

9.5 Example 5: Vertical heat conduction modelling

In this example, we simulate a temperature profile using the formation thermal conductivities and a reference temperature. The different files (Table 36) for this example are located in the 'Tutorials\WirelineWorkflow\4_Modelling\' folder.

Table 36: List of files for the 'GeoTemp Conduction Modelling' example

Function	Filename
Wireline temperature log	MyWell2.las
Lithology	MyWell_LithologyModelling.xls
BHT measurement	MyWell_BHTData.xls
Thermal conductivity measurement	MyWell_ThermalConductivityData.xls
Reservoir intervals	MyWell_ReservoirInterval.xls

The different steps to follow for loading of the data and the calculations are described in the GeoTemp Conduction Modelling section and are not repeated here. Once the data have been loaded and the parameters entered, the ‘GeoTemp Conduction Modelling 1.0’ window should be similar to the one given below (Figure 36). The temperature profile generated with a heat flow of 70 mW m^{-2} is available in the ‘MyWell_TemperatureLogOutput.xls’ file. The temperature values at reservoir intervals are available in the file ‘MyWell_ReservoirInterval_full.xls’.

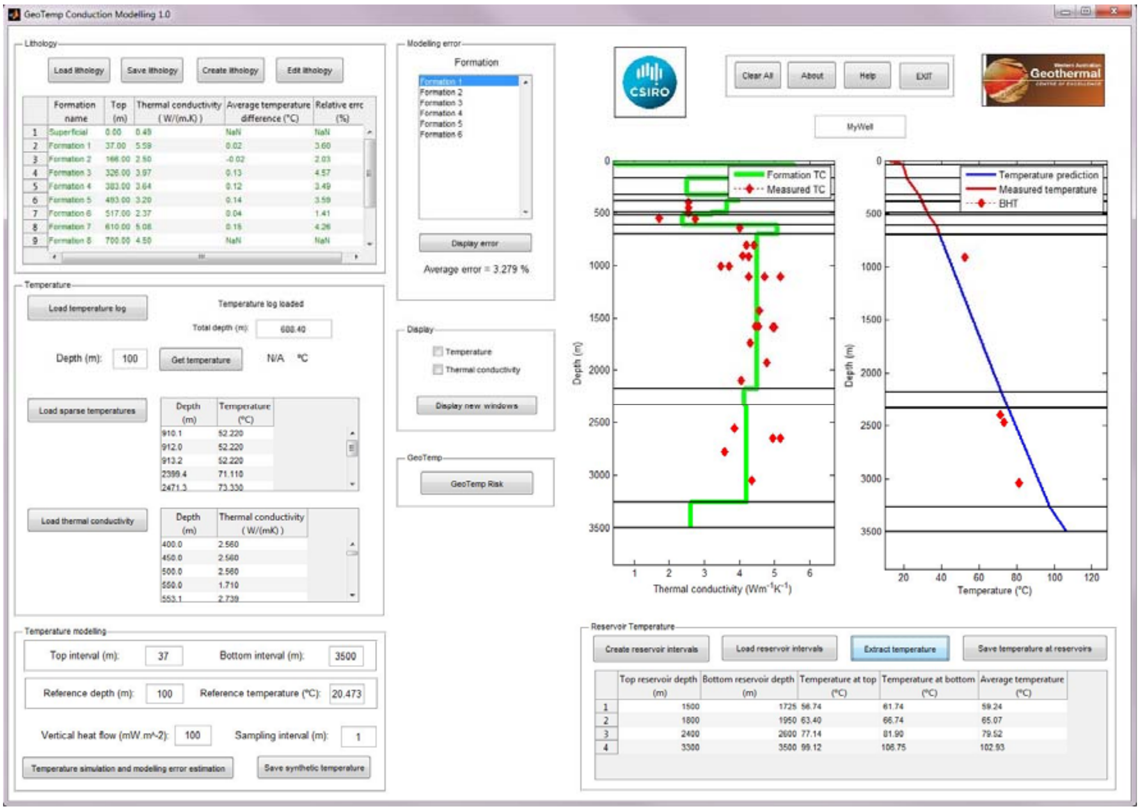


Figure 36: Example 5 results.

9.6 Example 6: Temperature simulation with uncertainties

In this example, we simulate temperature profiles with known uncertainties of the thermal conductivities per formation and vertical heat flow.

The different files (Table 37) for this example are located in the ‘Tutorials\WirelineWorkflow\5_Risk\’ folder.

The different steps to follow for loading of the data and the calculations are described in the GeoTemp Risk section and are not repeated here. Once the data have been loaded and the parameters entered, the ‘GeoTemp Risk 1.0’ window should be similar to the one given below (Figure 37). The temperature values at reservoir depths are available in the ‘MyWell_ReservoirInterval_full.xls’ file. The results for depth and temperature targets are available in the ‘MyWell_RiskDepth.xls’ and ‘MyWell_RiskTemperature.xls’ files. The temperature profiles simulated are available in ‘MyWell_TemperatureLogRiskOutput.xls’.

Table 37: List of files for the ‘GeoTemp Risk’ example

Function	Filename
Wireline temperature log	MyWell2.las
Lithology	MyWell_LithologyRisk.xls
Discrete measurement	MyWell_TemperatureData.xls
Thermal conductivity measurement	MyWell_ThermalConductivityData.xls
Reservoir intervals	MyWell_ReservoirInterval.xls
Depth targets	MyWell_RiskDepth_empty.xls
Temperature targets	MyWell_RiskTemperature_empty.xls

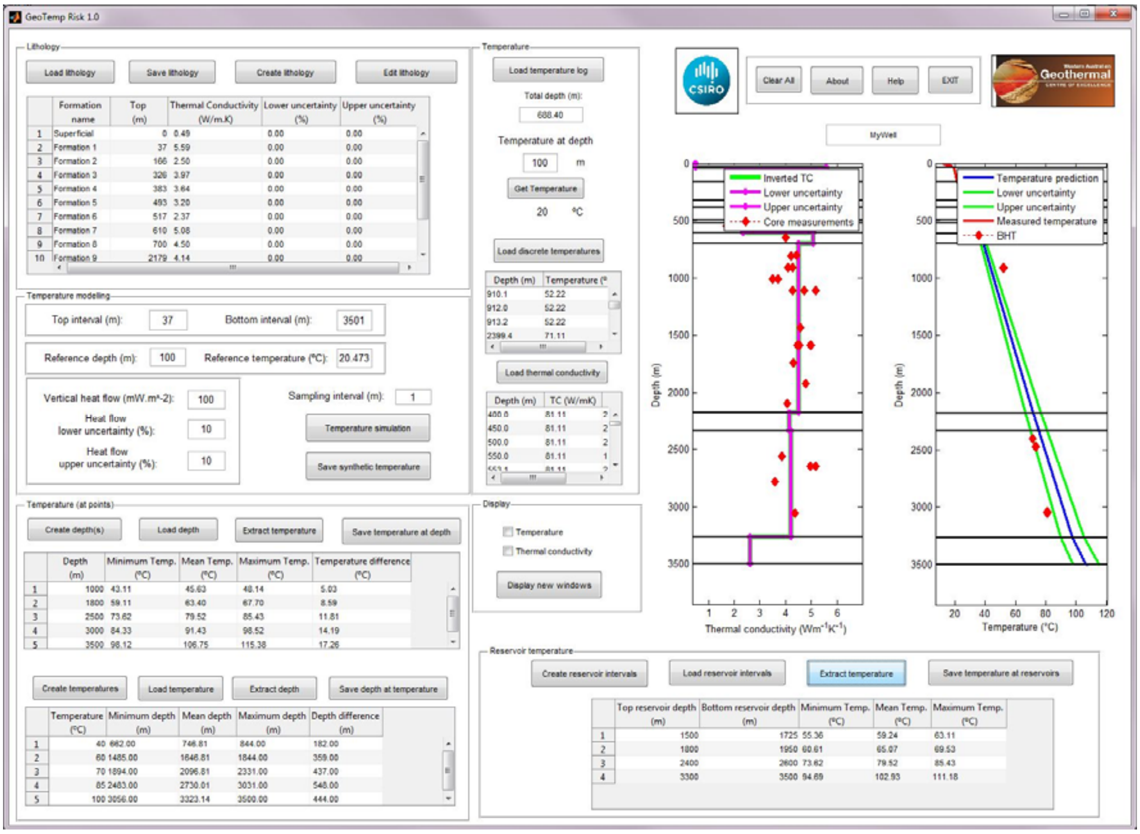


Figure 37: Example 6 results.

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