1.0 Formation Temperature Analysis (TP-Fit Software) User Guide

Manual Information

Author(s):	M. Heesemann
Reviewer(s):	M. Hastedt (1/17/09), Z. Mateo
Tech Writer(s)/Editor(s):	K. Graber
Supervisor Approval (Name, Title, Date):	
Manager Approval (Name, Title, Date):	
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1.1 Introduction

Overview

The TP-FIT software and penetrating downhole tools estimate the undisturbed physical condition of unconsolidated or semi-consolidated sediments. During the DSDP, ODP, and IODP programs, many tools were developed and deployed to measure formation temperatures and pore pressures. All of these measurements exhibited a transient character because of the penetration induced disturbances of the formation and the time constraints that did not allow reestablishment of equilibrium conditions. Over the years, different software solutions were developed to extrapolate the transient data to undisturbed values. Even though the code and the user interfaces of the various programs are at different stages of development and sophistication, similar algorithms, based on the processing of marine heat flux measurements are used in all programs. The measurements are compared with modeled data (e.g., analytical, numerical, or analog models) for which the undisturbed state is known. The fundamental difference between all of the programs is the model used, which has to take into account the geometry of the probe being used (chapter 3 in Heesemann, 2008).

The aim of the TP-Fit software is to provide a unified basis to process all of the different data types, described above.

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1.1 Introduction, Continued

Overview, cont.

The latest TP-Fit software is designed to work with APCT tool data and was especially developed to make use of the enhanced data quality of the APCT-3 tool. Since there is no difference in tool geometry between the APCT-3 and earlier versions of the APCT, the software is able to handle data from both tools. Additionally, the software was developed to be easily used with data from other tools.

1.2 APCT-3 Processing Quick Start

Processing

Sediment thermal conductivity = k

Heat capacity = ρc

To process data, perform these steps:

Step	Action
1	Put APCT-3 data in a working directory with the *TPFit.m* code (and subdirectories) and start Matlab®. Run *TPFit*.
2	Unzip TP-Fit in dedicated Program directory and run TP-Fit.m within Matlab (this automatically installs/sets up TP-Fit). (See ***Overview on page 1-21***).
3	Create separate directory for working with the data (preferably one directory per site).
4	Select **Load Data** to load a data file.
5	Select **Edit Meta-Data** and enter appropriate values. Be sure to enter values of k and ρc most consistent with initial expectations. Note: k and ρc contain reasonable defaults if you have no idea what to use. If you have a good estimate of k, use it and use **Compute** to come up with a value for ρc that matches k or enter ρc manually, if you also have a good constraint of ρc.
6	Select **Pick** and choose the tool penetration time (*t0*), the initial data point to fit to the model (*Data Start*), and the final data point to fit to the model (*Data Stop*).
7	Select **Show Fit** and examine the *Results* plot window. Return to **Edit Meta-Data** and **Pick** as needed to examine different properties and data intervals.
8	Select **Compute Contours** and the program will complete the same calculations using all available values of k and ρc. When this is complete, select **Explore** to evaluate the influence of sediment physical properties in fit statistics, equilibrium temperatures, and other parameters.
9	Select **Save Session** to create a Matlab® *mat* file, or **Make Report** to generate text output for later plotting.

1.3 Using TP-FIT Software

Overview

This section provides an overview of the TP-Fit3 software functionality. TP-Fit is a Matlab™ program created for processing APCT-3 data. TP-FIT will also work with older data, provided they are properly formatted, because the geometery of the new APCT tool is essentially identical to that of the second-generation tool.

The software file name is tpfit3.exe. The TP-FIT3 workflow consists of:

- Launching TP-FIT3 program
- Importing Data
- Editing Meta Data
- Picking Data
- Inspecting Fit
- Computing Contours
- Saving Results

General Conventions

Instructions for *TP-Fit* follow some general conventions:

- Typed commands are listed in **bold**.
- In almost all cases, after entering something at the keyboard, you need to press the <**enter**> or <**return**> key (or select the **Enter** button or the **OK** button in a pop-up window). Occasionally you may need to press a special key or button (identified by placing the key name inside <triangular brackets>).
- You may need to select a menu or window item listed in this manual in italics. [**NB**: most *TP-Fit* functions can be run without the graphical user interface, from the Matlab® command line, but all instructions herein assume the user is running TP-Fit using the Graphical User Interface.

Launching TP-Fit Program

1. If Mat.Lab™ is installed on your computer, start Mat.Lab™ and open the working directory. This directory should contain the main *TPFit.m* script and folders (subdirectories) called *RefModels* and *TP-Fit*. It's best to have a single working directory for an expedition. Bring data files into this directory for processing and then move the files out of the directory when work is completed.

   Note: If Mat.Lab is not installed on your computer, ask the Help Desk (shore) or Marine Computer Specialists (ship) to install the software. ***APCT-3 Data Modeling and Processing on page 1-18*** has detailed instructions on installing TP-Fit3.

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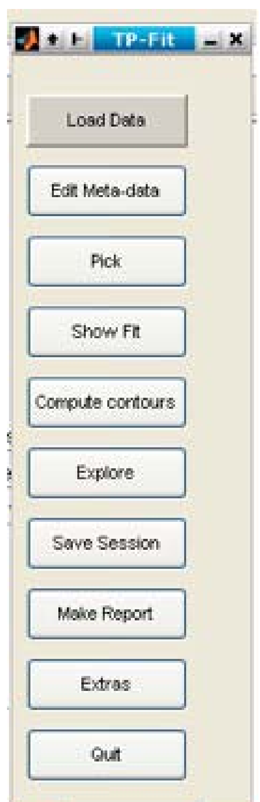
1.3 Using TP-FIT Software, Continued

Launching TP-Fit Program, cont.

2. Double click the *TPFIT3.exe* icon on the desktop or the *TPFit.m* script in the TP-Fit\MatLab™ directory within Matlab™ to launch the graphical user interface (GUI).
3. When the program opens, a narrow window with 10 rectangular buttons appears. The buttons represent the general work-flow process. Usually the buttons are used from top to bottom (see Figure 1-1). This screen remains open as the different command button windows are used. The button command names are:

- Load Data
- Edit Meta Data
- Pick
- Show Fit
- Compute Contours
- Explore
- Save Session
- Make Report
- Extras
- Quit

Figure 1-1. TP-Fit Opening Screen Before Loading Data (by Hesseman et al. 2007).



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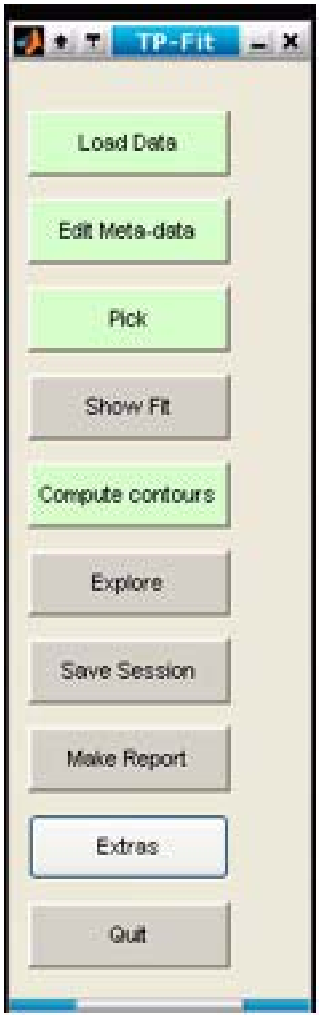
1.3 Using TP-FIT Software, Continued

Load Data

1. The **Load Data** button allows you to import data to begin processing (e.g., the APCT-3 file 1329C09H.dat from the test data directory).
2. Once a Session file is loaded, the **Pick** and **Compute contours** buttons will turn green (*Fig. 1-2, p. 1-6*).

   It is possible to import APCT (*.dat), APCT-3 (*.dat) , DVTP (*.eng) data, and SET and SETP (*.dat) data. Moreover, saved sessions (*.mat) can also be loaded, depending on how the session was saved.

Figure 1-2. TP-FIT Opening Window After Loading Data (by Heesemann et al., 2007).



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1.3 Using TP-FIT Software, Continued

Edit Meta Data

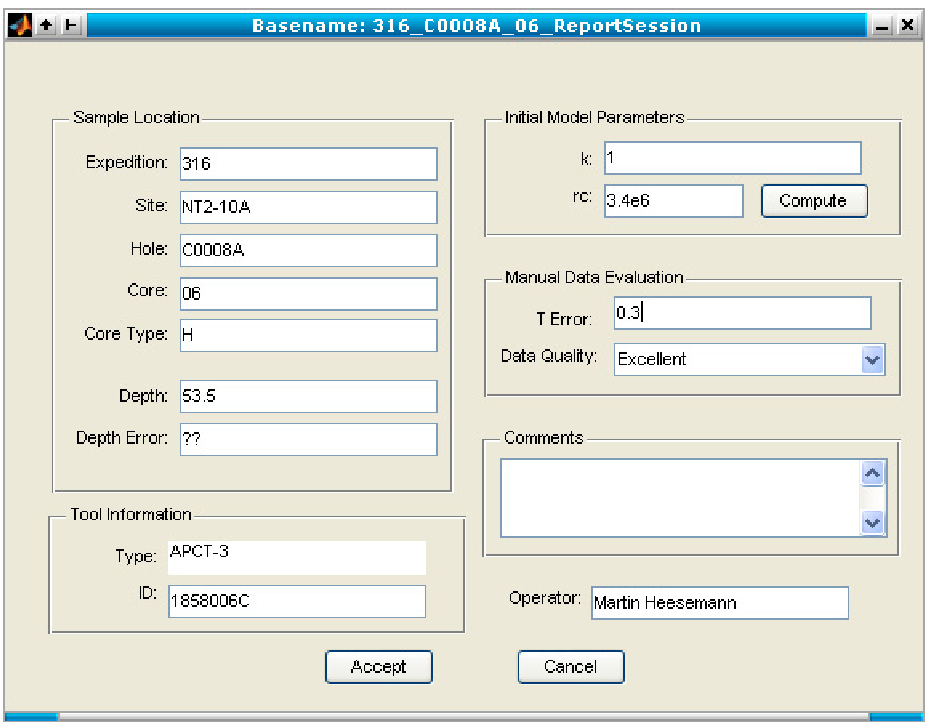
After the data are successfully uploaded, the basic meta data is created, and the Load Data and Edit Meta-data buttons on the opening window are green, the Edit Meta-data window opens (Figure 1-3).

The data in the Edit Meta data window are provided as a header in the ASCII report generated by "Make Report." The report results are uploaded into the IODP database. Initial values are already entered on the basis of the data file and the last values saved when the program was used. On first use, the fields are blank or contain reasonable defaults.

If any data is missing from a field, add the data. Initial *k* and Initial ρc values are standard physical property values used in calculations and are supplied by the program.

Note: Do **not** change these values unless you know the values for the area.

Figure 1-3. Edit Meta Data Screen



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1.3 Using TP-FIT Software, Continued

Edit Meta Data, cont.

Once the operator enters/reviews the data in the Edit Meta data screen (see ***Fig. 1-3, p. 1-7***), click **OK.** A data plot screen is generated (see Figure).

Part of data processing is evaluating the uncertainty in final temperatures caused by the uncertainty in *k* and *rc* values, but it is best to enter a reasonable value. In the last generation of APCT processing software, the user was asked to enter only a value for *k*, and thermal diffusivity (K= *k/rc*) was calculated from the empirical relation of Von Herzen and Maxwell [1959]:

$$K = 3.657 \times (k-0.70)/10-7$$

where *k* is in W/m-k and K is in m^2/s.

Other studies have explored relations between *k* and K, and the user is advised to choose a favored relation initially, but to explore the significance of this relation as part of APCT processing, as described below. Choose **OK** to close the *Edit Meta-Dat*a window.

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1.3 Using TP-FIT Software, Continued

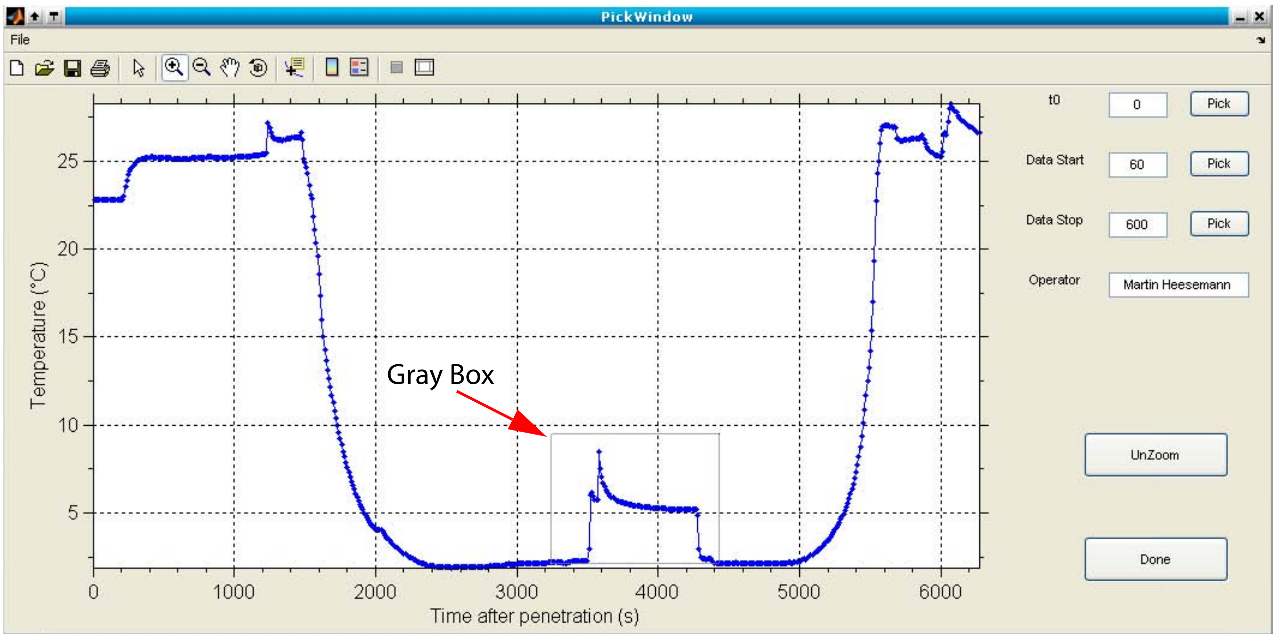
Pick Data

The next step is to select the data segments to process. Three data points must be selected:

- Tool penetration time (labeled *t0*)
- Data start (initial data point to fit to the model)
- Data stop (final data point to fit to the model)

Click **Pick** on the opening window. A plot window opens showing the complete data record (Figure). The data are shown in a standard Matlab plotting window, therefore you can zoom in and out, and adjust axes. *TP-FIT* assumes a data window of 9 minutes (from 60 s to 600 s after penetration) to process. Both of these times can be adjusted by choosing the appropriate **Pick** button shown in the upper right hand side of Figure 1-4.

Figure 1-4. Complete Record Pick Data Plot.



Zoom in on the window (gray box, Figure 1-4) of data that starts before penetration and ends after penetration, including several minutes of data prior to tool penetration.

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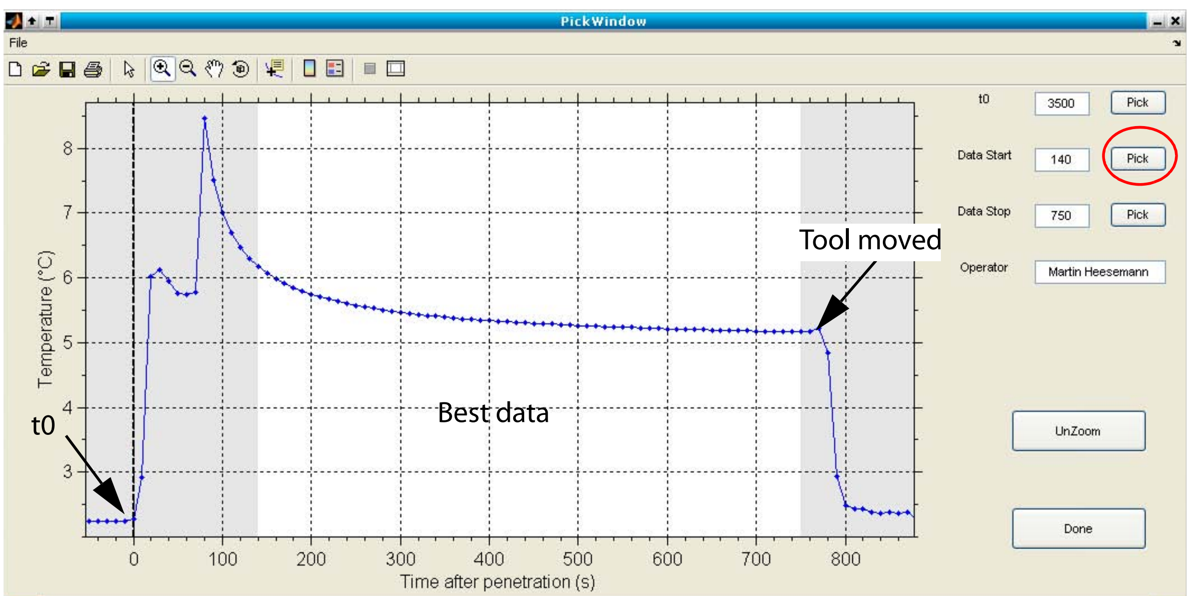
1.3 Using TP-Fit Software, Continued

Pick Data, cont.

Tool Penetration Time and Data Start

1. Click the **Pick** button next to the *t0* box in the *Data Plot* window.
2. Move the cursor to the point you would like to select to represent the time of tool penetration.
3. *Left-click* with the mouse. This function provides the operator with a crosshair to select the penetration time (t0) on the *Data Plot* window (this region is reused in the result plots later).
4. Refine the picks by selecting an interval in the unshaded region (see ***Fig. 1-5, p. 1-10***) of the plot. Pick an area with the most consistent data, but the pick should not be too close to *t0*. TP-FIT shifts the time between penetration and the data window as part of the processing, thus, selection of exactly the right penetration time is not essential.
5. Next select the Data Stop point.

Figure 1-5. Zoom of Data Plot showing t0 and the Best Data Area Author: replaced old figure with one of new ones you sent. This new figure seems very similar to 1-6 now. Should there be a different figure for 1-5?.



Data Stop

The next step is to pick the end time (which is 600 in Figure 1-5). You want clean data so it is best to pick the value a little left of the point where the temperature rapidly changes (rapid changes indicate the tool is moving). Once the *t0*, *Data Start,* and *Stop* points are selected, click **Done.** The window closes, returning you to the opening window, where the Pick button (see ***Fig. 1-2, p. 1-6***) will now be green.

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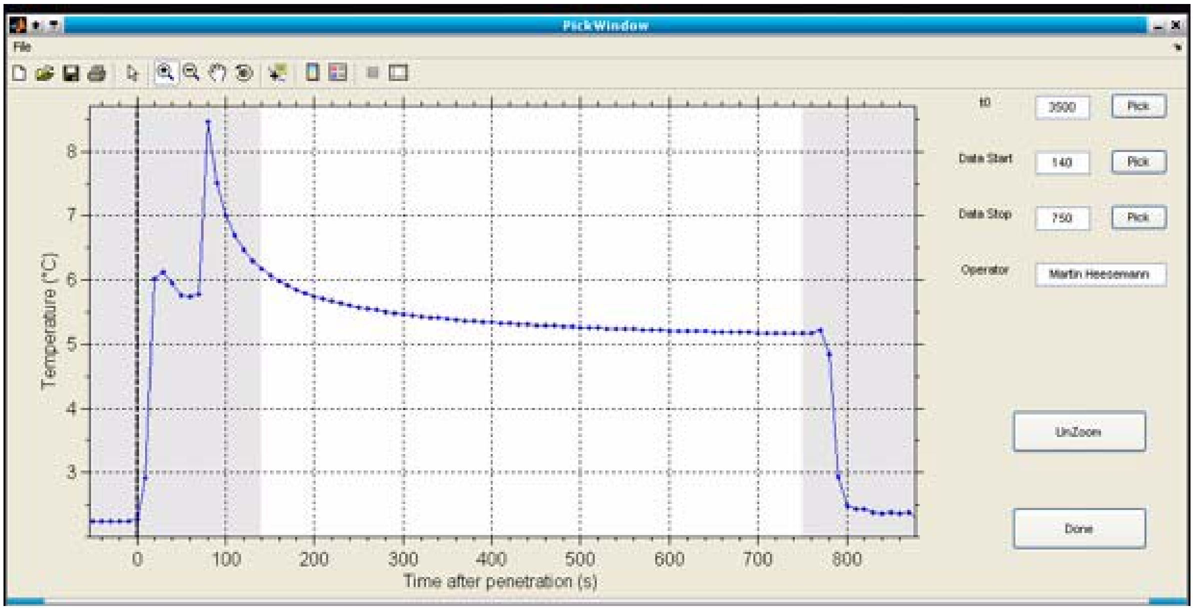
1.3 Using TP-FIT Software, Continued

Figure 1-6. Zoomed In View of Best Data Area.

Zoomed view of Best Data Area.



Inspect Fit

The **Show Fit** button in the opening screen provides an initial result graph (labeled *Results*) window containing four subwindows (see ***Fig. 1-7, p. 1-12***).

(A) Shows the measurements (blue dots), the selected data (unshaded region) and the last third of the selected data (starting at the diamond). The reference model corresponding to the physical properties (shown in lower right plot) is represented by a bold red line and extrapolated temperatures are shown as dashed and dotted lines.

(B) Shows the difference between data and model and reveals systematic deviations that cannot be recognized in the first plot. The deviations are plotted on a log-scale, as absolute values, with overestimates and underestimates shown with open and filled symbols, respectively.

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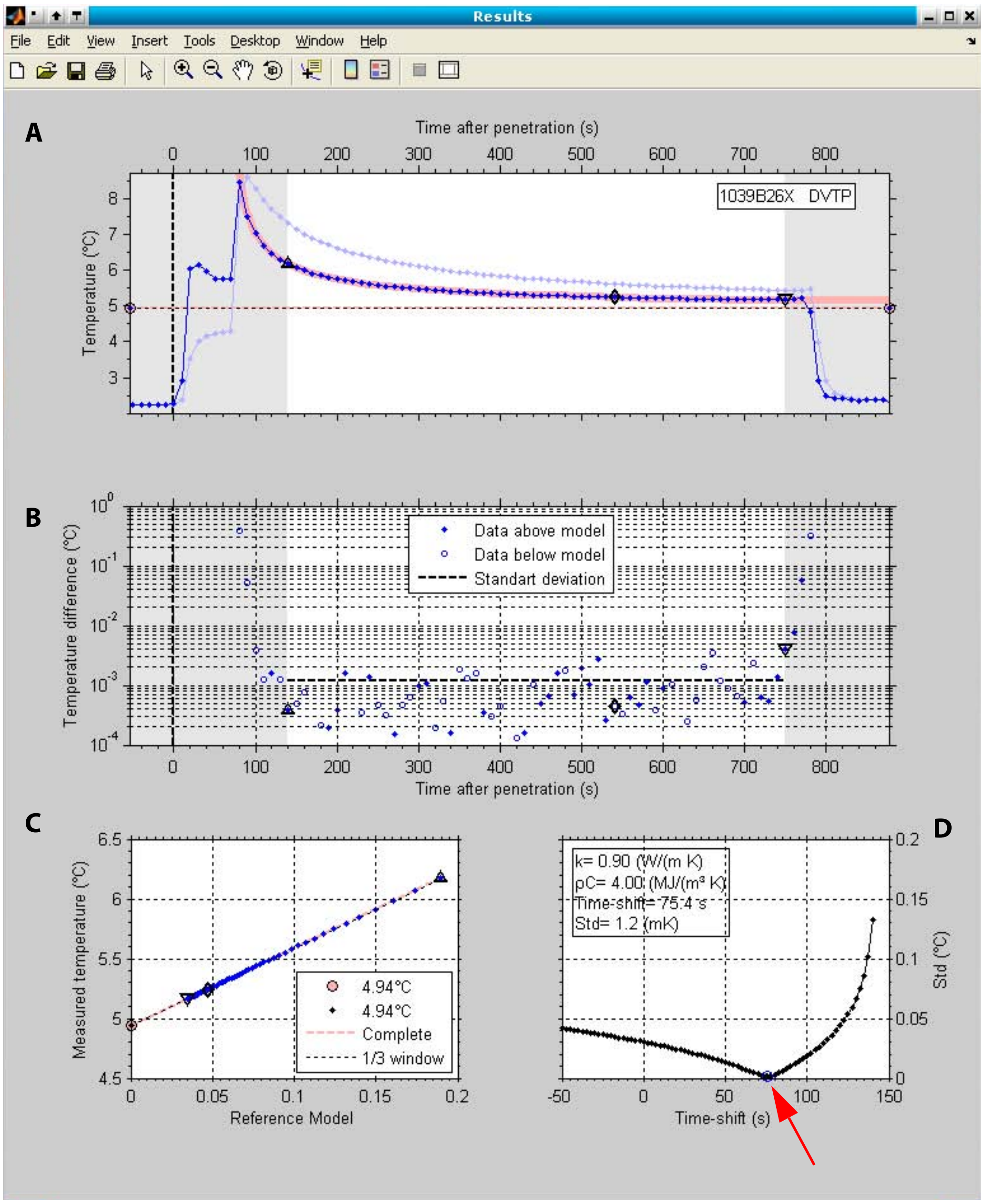
1.3 Using TP-FIT Software, Continued

Inspect Fit, cont.

Figure 1-7. Results Window.



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1.3 Using TP-FIT Software, Continued

Inspect Fit, cont.

Sections C and D (Figure 1-7) show how the equilibrium formation temperature was estimated.

(C) Shows a cross plot of measured and modeled temperatures. Early data appear on the upper right corner of the plot and later data appear towards the lower left corner. Extrapolation of the (hopefully) linear trend shown in this plot back to the x = 0 value, indicates the interpreted formation temperature at equilibrium (i.e., what the tool would have recorded eventually, if it were left in place long enough). Two values are indicated:

- Dashed pink line indicating use of the full data window
- Dotted black line using the last third of the data window

(D) Shows the standard deviation (black line with dots) of the misfit between the model and observations. The optimal time-shift used in the previous plots is marked by a blue open circle (red arrow, Figure 1-7D). After a mouse click into the axes, a dashed and a dotted line show up. Theses lines show the sensitivity of estimated undisturbed formation temperatures to time-shift changes. Clicking the *time-shift* axis allows the user to inspect the effect of different time-shifts on all graphs. Clicking on the *parameter box* (Figure 1-7D) opens a new window where it is possible to change the model parameters k and ρc by moving the crosshair on the displayed graph

Save and Make Report

If you are satisfied with the processing at this stage and would like to save your work, click the **Save Session** button on the opening TP-FIT rectangular window (the one with the green buttons) to put the workspace into a Matlab™ mat file that can be reloaded later.

You can also send results of the fit analysis to a text file for plotting with different software by clicking **Make Report** in the opening window. *Make Report* creates eps files of the current result and contour plots in the data directory and generates a simple ASCII report.

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1.3 Using TP-FIT Software, Continued

Compute Contours

The **Compute Contours** button starts the program cycling through all available models, using a range of *k* and ρc values, and calculates the best-fitting, equilibrium temperatures for each model.

Models are available (p. 63 in Heeseman, 2008 and TP-Fit Folder: \Matlab\TP-Fit\RefModels) for $0.5 \leq k \leq 2.5$ W/m-k, and $2.3 \times 10^6 \leq \rho c \leq 4.3 \times 10^6$ J/m^3-K, in increments of 0.1. This range of values should accommodate the needs of most APCT-3 tool users.

Explore

When the calculations performed by the **Compute Contours** button are complete, click the **Explore** button to see the results of the analysis. You are presented with four contour plots in a new plot window labeled *Contours* (*Fig. 1-8, p. 1-15*): standard deviation, estimated temperature, time-shift, and window-based delta T.

On all contour windows, the star shows the *k* and ρc values that minimize the standard deviation of the misfit between model and observations, and the white dot shows the currently-selected value. If you look back at the *Results* window, you will see that it has been updated to show values of *k* and ρc consistent with the position of the red star. You can select different values of *k* and ρc by moving the cursor over the top plot on the *Contours* window and left-clicking with the mouse. The white dot will move and, once again, the *Results* plot is automatically updated.

A mouse click into one of the contour plots will move the white dot and the results of the corresponding physical properties will be displayed in the *Results* plot window. The red star represents the smallest standard deviation. The valid physical properties for the result plot are not continuous. Values are rounded to the closest tenth of the physical properties.

Note: If you change the picks of the used data window, the contour data should be recalculated as it does not refresh automatically.

Contour Plot A

The top plot (A) shows the smallest standard deviations achieved by least-squares best-fitting of each combination of *k* and ρc values. For high-quality data (rapid tool penetration, no motion during 8-10 min penetration), the smallest standard deviation may be 0.01°C or less. This is the standard deviation of a particular fit of data to a function, not an uncertainty in the equilibrium temperature. To decide what may be an appropriate uncertainty, look at the next plot (B).

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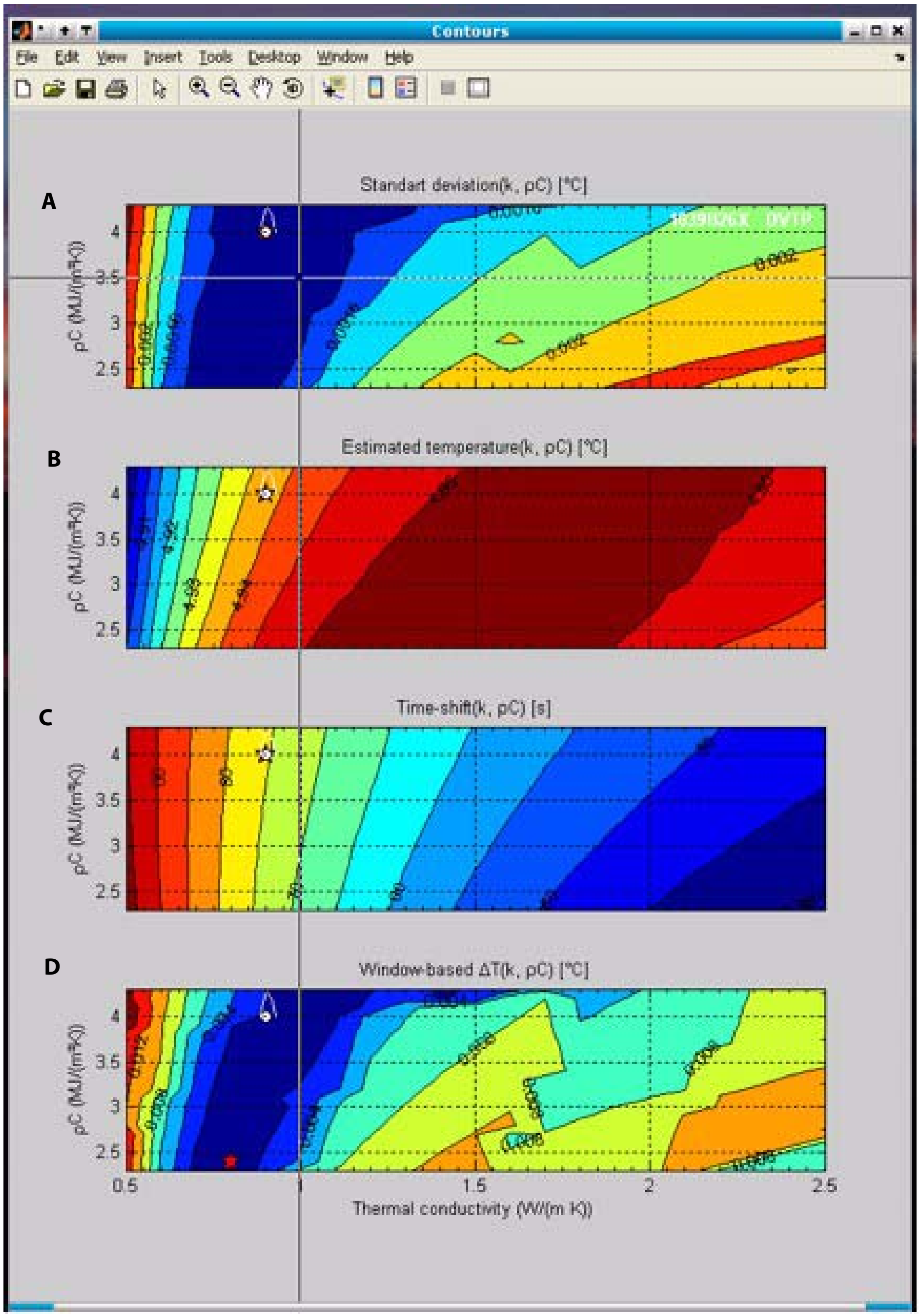
1.3 Using TP-FIT Software, Continued

Explore, cont.

Figure 1-8. Four Contour Plots in the Contour Window after Clicking Explore Author: should Ireplace this figure with contours01.pdf. The 2 figures are not exactly the same**?.**



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1.3 Using TP-FIT Software, Continued

Explore, continued

Contour Plot B

Contour Plot B shows the equilibrium temperature as a function of k and ρc. For high-quality data, there may be a range of ±0.1-0.2 °C or more in equilibrium temperatures based on selection of reasonable values of k and ρc. This is a more reasonable estimate of uncertainty in the final value (assuming high-quality data and a good fit of observations to the model).

Contour Plot C

The third plot shows how the best-fitting time shift in penetration time varies with k and ρc values.

Contour Plot D

The fourth plot shows the difference between final temperatures calculated on the basis of the entire data window and those based on using only the final third of the data window.

Advanced Features

The *Extras* button provides some interesting features and debugging tools, which can be used at any time. If you moved and resized the figure windows it is possible to save the positions. It is also possible to export the current data structure to the work-space "Data" and inspect how information is added from step to step, or to make a simple screen dump of the data.

Note: Be careful if you want to import "Data" from the workspace!

Setting Equilibrium Temperature

A few comments on selecting an equilibrium temperature. None of the information shown on the contour plots can be used by itself to determine the "true" insitu temperature of the formation. In many cases, the properties that provide the best-fit of the model to data may be unrealistic, for example, sometimes including very high values of k and ρc. The difficulty in selecting an appropriate model (and equilibrium temperature) is that, although the new models are better than the old models in replicating the tool geometry, there are aspects of each deployment that remain poorly constrained, including:

- Distribution of frictional heating
- Heterogeneities in the formation
- Quality of the thermal contact between the shoe and sensor probe
- Creation of a damaged zone around the shoe.

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1.3 Using TP-FIT Software, Continued

Setting Equilibrium Temperature, cont.

Because these (and likely other) characteristics of each deployment are not well characterized, available parameters (k, ρc, and the time shift) may end up being "adjusted" to accommodate the data and improve the fit statistics.

In summary, a good fit of the data to the model does not demonstrate that the model (or the equilibrium temperature) is correct. Similarly, the model that provides the statistical best fit to the data is not necessarily most likely to be correct. Ultimately, researchers will need to use all available data, particularly physical properties measurements from around the APCT measurement depth, and empirical relations between k and ρc and consider whether an inferred equilibrium value makes sense in the context of other measurements

1.4 APCT-3 Data Modeling and Processing

Modeling and Other Considerations

Processing APCT-3 temperature data to determine insitu conditions cannot be done automatically, but requires careful and somewhat subjective fitting of measured temperatures to theoretical decay curves. Some general understanding of the physics involved is required to make good interpretations. The processing procedure described in the following section assumes the reader understands the general theory behind APCT measurements, as described by Horai and Von Herzen (1985), Horai (1985), and Heesemann et al. (2007). Additional insight is provided by papers describing processing of subseafloor probe data using tools with differing geometries (e.g., Bullard, 1954; Davis et al., 1997; Hartmann and Villinger, 2002; Langseth, 1965; Villinger and Davis, 1987).

Tool Responses During Deployments

Before moving to the processing procedure, a brief review of tool responses during typical deployments (Fig. III-1 WHERE IS THIS FIGURE? Heesemann wrote there are figures in his dissertation. Author: Please provide specific figure # to include from the dissertation for these figs.) is required. Measured temperatures drop as the APCT-3 is deployed from the ship and lowered to the seafloor. The lowest measured temperature may be found close to the seafloor, but as described earlier, this temperature may not be consistent with the bottom water unless the tool is held stationary just above the mudline for 10-15 min with the pumps off. The tool is lowered to the bit, pressure is accumulated in the drill string, and the core barrel is fired into the mud. There is an abrupt temperature rise associated with frictional heating of the coring shoe, and (for most stations) the tool temperature begins to decay toward the true insitu temperature (Fig. III-1A). For stations in unusually warm sediments, the tool temperature may continue to rise after penetration (Fig. III-1C). It is not possible to leave the tool in the seafloor long enough to achieve complete equilibration as this would require 40-60 min or longer, which risks loss of the tool (and the APC core barrel) as sediments settle around the core barrel. Instead, partial equilibration is achieved, and the core barrel is recovered by wireline (see Heesemann, 2008 for data examples).

Data Extrapolation

Processing of APCT-3 data to infer the insitu formation temperature requires extrapolation of a short record of thermal equilibration. The programs used for this purpose with the first- and second-generation APCT tools were based on the assumption that tool response was consistent with a one-dimensional, radial geometry (Horai, 1985). Fitting data to a model based on this geometry is based on the assumption (proven to be largely accurate) that radial heat transfer away from the tool is much more important than vertical heat transport along the tool, and that the temperature probe is sufficiently far from the end of the coring shoe that there is little influence associated with the contrast in properties between the shoe and deeper sediment.

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1.4 APCT-3 Data Modeling and Processing, Continued

APCT-3 Cooling Curves

As part of the development of the APCT-3 system, new cooling curves were calculated numerically on the basis of the geometry of the coring shoe and core barrel. In addition, earlier programs were based on a fixed, analytical relationship between sediment thermal conductivity (k) and heat capacity (ρc). New cooling curves were calculated using a wide range of k and ρc values, allowing the user to select the most appropriate values and to explore the influence of parameter selection interactively.

General Procedure

The general procedure to process downhole temperature data is to select:

- Formation properties
- Data interval to be processed
- Shift tool penetration time to minimize statistical misfit between measurements and model.

Once an appropriate fit is achieved, temperatures are extrapolated to infinite time, using the model, to infer the insitu formation temperature. Users typically neglect the first 30-60 s of data following penetration, as these measurements often deviate from theory for several reasons, including the noninstantaneous and variable rate of tool penetration, and the nonuniform distribution of frictional heat. The data interval selected for processing is usually no longer than 7-9 min, sometimes less, in part because of limited time with the tool motionless in the seafloor, but also because deviations of tool cooling from the theoretical model tend to occur at later times.

Challenges with Selecting Formation Properties

Selection of formation properties is challenging for several reasons:

1. Sediment thermal conductivity is heterogeneous in many formations.
2. DSDP, ODP, and IODP scientists typically do not determine sediment heat capacity, and there is no single relation between thermal conductivity and heat capacity that applies for all sediments.
3. Thermal conductivity measurements are virtually never made at exactly the same location as the temperature probe, and even, if they are recovered sediments from the coring shoe are often highly disturbed.

Thus researchers must be prepared to process data using a variety of reasonable properties, and to list insitu temperatures determined through processing with uncertainties that span a range of values.

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1.4 APCT-3 Data Modeling and Processing, Continued

Time Shift

The time shift applied during processing to optimize the statistical fit between observations and model calculations has a long history in analysis of seafloor heat flow data [e.g., Bullard, 1954; Davis et al., 1997; Hartmann and Villinger, 2002; Langseth, 1965; Villinger and Davis, 1987]. The time shift is a heuristic representation of several properties and processes that are virtually impossible to predict a priori:

- Finite tool insertion time
- Irregular heating
- Creation of a damaged zone around the coring shoe (inside and/or outside) having different sediment properties
- Fluid movement away from the tool for a brief period after penetration.

Experience has shown that it is often difficult to achieve a good fit between observations and modeled temperature decay without allowing for the time shift. However, this additional degree of freedom in data processing can also accommodate use of a theoretical model that is inconsistent with actual tool and formation geometry or properties. We do not have much experience yet with the new APCT-3 cooling curves and a detailed comparison of older and newer decay curves remains to be completed and their influence on inferred insitu temperature determined, but it appears that time shifts required to "best-fit" the data using the new model may be somewhat shorter than those needed with the older models. This indicates that the newer models may do a better job representing experimental conditions.

Data Quality

It is also important in selecting a data interval during processing to examine the experimental data very carefully and to avoid data segments showing evidence of tool motion. In some cases, the tool is moved abruptly and this results in a second heating pulse that is clearly visible, but in other cases, there can be a subtle change in the rate of cooling. If data are used in processing that include secondary heating because of tool motion, a spurious formation temperature may be inferred. This issue illustrates one of the great challenges in processing APCT data in general: a high-quality statistical fit does not ensure the extrapolated formation temperature is correct. Experience has shown that, in many cases, extrapolated temperatures from what appear to be excellent records are inconsistent with insitu temperatures determined at higher and lower depths (i.e., an extrapolated value falls off an otherwise consistent thermal gradient). Sometimes the conundrum can be resolved by reexamining the questionable data record, but in other cases, the reason for the inconsistent extrapolated temperature remains enigmatic.

1.5 Working with Reference Models

Overview

This section describes how to work with TP-Fit reference models. Author: please provide a brief summary paragraph of what this is and how it is used. The following processes are described:

Processes	See page....
Load Reference Model Tables	*1-21*
The Table Structure	*1-21*
High Level Reference Model Access	*1-24*
Graphical Model Comparison	*1-26*

Load Reference Model Tables

TP-Fit reference models are stored in look-up tables that are stored in Matlab *.mat files on disc. It is possible to load the tables by using the Matlab load function or by dragging and dropping the *.mat files, containing a single structure variable M, on the command window.

We recommend using the **LoadModel (ModelType)** function (type **help LoadModel** for details), to access these models (Author: type this where?). If the model locations or names will change, only LoadModel has to be adapted to keep all dependent~~ing?~~ code working.

To load the DVTP reference temperature table type:

```
M = LoadModel ( 'DVTP_T');
```

The APCT table can be loaded using

```
10M = LoadModel ('APCT_T');
```

The Table Structure

The lookup table structure M contains the following fields:

```
M
```

```
M =

    ks: [1x21 double]
    rcs: [1x21 double]
    k: [21x21 double]
    rc: [21x21 double]
    T: {21x21 cell}
    t: [1x201 double]
```

Info: [1x1 struct]

The vectors ks and rcs contain a list of all different sediment thermal conductivities (ks) and volumetric heat capacities (rcs) provided in the lookup tables. See the following subsets of ks and rcs:

```
ks=M.ks([1:3 end-1:end])
rcs=M.rcs([1:3 end-1:end])
```

ks =

0.5000 0.6000 0.7000 2.4000 2.5000

rcs =

Columns 1 through 4

2300000 2400000 2500000 4200000

Column 5

4300000

The tables (matrices) k and rc contain somewhat redundant information and are provided for security/convenience. They contain the values in ks and rcs ordered in a 2D lookup table (k increasing with rows and rc increasing with columns). Compare the results of the following commands with the ks and rcs printed above:

```
i=3;
j=2;
k=M.k(i,j)
rc=M.rc(i,j)
```

k =

0.7000

rc =

2400000

A vector of reference temperatures corresponding to k and rc can be retrieved by:

```
T=M.T{i,j};
```

Temperatures are stored in an array of cells ({i,j} and not (i,j)!!!). The DVTP model also contains the field T2 which contains model temperatures at the location of the second thermistor.

The model times, stored in the vector M.t, are not necessarily equidistant! Most models use a logarithmic time scale:

```
t=M.t;
tStart=t(1:3)
tEnd=t(end-2:end)
TStart=T(1:3)
TEnd=T(end-2:end)
```

```
tStart =

    0    0.0100    0.0108


tEnd =

    1.0e+005 *

    0.8504    0.9222    1.0000


TStart =

    1.0000    1.0002    1.0002


TEnd =

    0.0011    0.0008    0.0005
```

Furthermore, **LoadModel** adds the location from where the model was loaded to the **M.Info** field which can contain also other optional information regarding the model:

```
M.Info.ModelFile
```

```
ans =

D:\home\martin\TODP\APC3\TP-Fit\MatLab\TP-Fit\RefModels\APCT_TModels.mat
```

High Level Reference Model Access

The model table structure, contained in M, is difficult to handle, since times are not equidistant, and the structure of the tables may change in the future. Therfore, it is recommended to access the reference models through the "high-level" function GetRefDecay, if possible!

Below, several examples of GetRefDecay calls are shown and the resulting RefData is compared in a plot.

If called without parameters **GetRefDecay** will use a set of standard parameters. An APCT temperature model with sediment thermal conductivity k=1 and volumetric heat capacity rc=3.5e6 will be returned. The temperatures T are still at the same times t (not equidistant) as in the model *.mat file. The Info field of the **M** structure (see above) is stored in the **ModelInfo** field.

```
RefData{1}=GetRefDecay;
disp(RefData{1});
```

```
                k: 1
               rc: 3500000
                t: [1x201 double]
                T: [1x201 double]
        ModelType: 'APCT_T'
        ModelInfo: [1x1 struct]
```

To get a reference model corresponding to certain parameters, both parameters have to be provided (**GetRefDecay(k,rc)**). If two output variables are requested, **GetRefDecay** also returns the table structure **M** that was loaded. The parameters have to be in the range of the table, otherwise NaNs are returned. If the parameters are in between table entries, the closest entries are chosen by default (see warning):

```
[RefData{2},M]=GetRefDecay(1.08,3.55e6);
k=RefData{2}.k
rc=RefData{2}.rc
```

```
Warning: k not in model lookup table. Unsing closest!

Warning: rc not in model lookup table. Unsing closest!


k =

    1.1000


rc =
```

3.6000e+006

It is also possible to interpolate between closest table entries (**,'InterpProps',true**) instead. But this "3D" interpolation is rather slow!

Also, for every call of **GetRefDecay** the reference table has to be loaded from disc. If you want to get many models from the ***same*** table it is possible to speed things up by retrieving the table (M) during the first call (see above) and reuse it with **(,'M',M)**.

```
RefData{3}=GetRefDecay(1.08,3.55e6,'InterpProps',true,'M',M);
k=RefData{3}.k
rc=RefData{3}.rc
```

k =

1.0800

rc =

3550000

All the data above is still at original model times. If you want the model at specific times (e.g. from 0s to 300s in 10s intervals), time interpolation is enabled using the **'ts'** parameter. Time interpolation is much faster than parameter interpolation (both types of interpolation can be combined!).

```
RefData{4}=GetRefDecay(2.08,4.2e6,'InterpProps',true,'ts',0:10:300);
```

To load a model other than the APCT temperature model the model type (see **LoadModel**) as to be specified, explicitly. Using the DVTP Model it is also possible to retrieve the temperatures of the second sensor (**,'GetT2',true**).

```
RefData{5}=GetRefDecay(1,3.5e6,'ModelType','DVTP_T','GetT2',true);
disp(RefData{5});
```

k: 1

rc: 3500000

t: [1x201 double]

T: [1x201 double]

T2: [1x201 double]

ModelType: 'DVTP_T'

ModelInfo: [1x1 struct]

To get a nice ASCII table of the reference model use the **Print** option (**,'Print',true**) if you specifiy an additional filename (**,'FileName','MyOutFile.dat'**) the ASCII-table is dumped to the file instead to the prompt:

```
GetRefDecay(1,3.5e6,'ts',[0:10:50],'Print',true);
```

APCT-3 Model: k= 1.00 (W/(m K)); rc= 3.50 (MJ/ m^3 K)

t (s)	T (°C)
0.000000	1.000000
10.000000	0.711148
20.000000	0.618901
30.000000	0.560470
40.000000	0.518053
50.000000	0.485129

Graphical Model Comparison

Ignore the following code and have a look at the figure below Author: then why include the code?

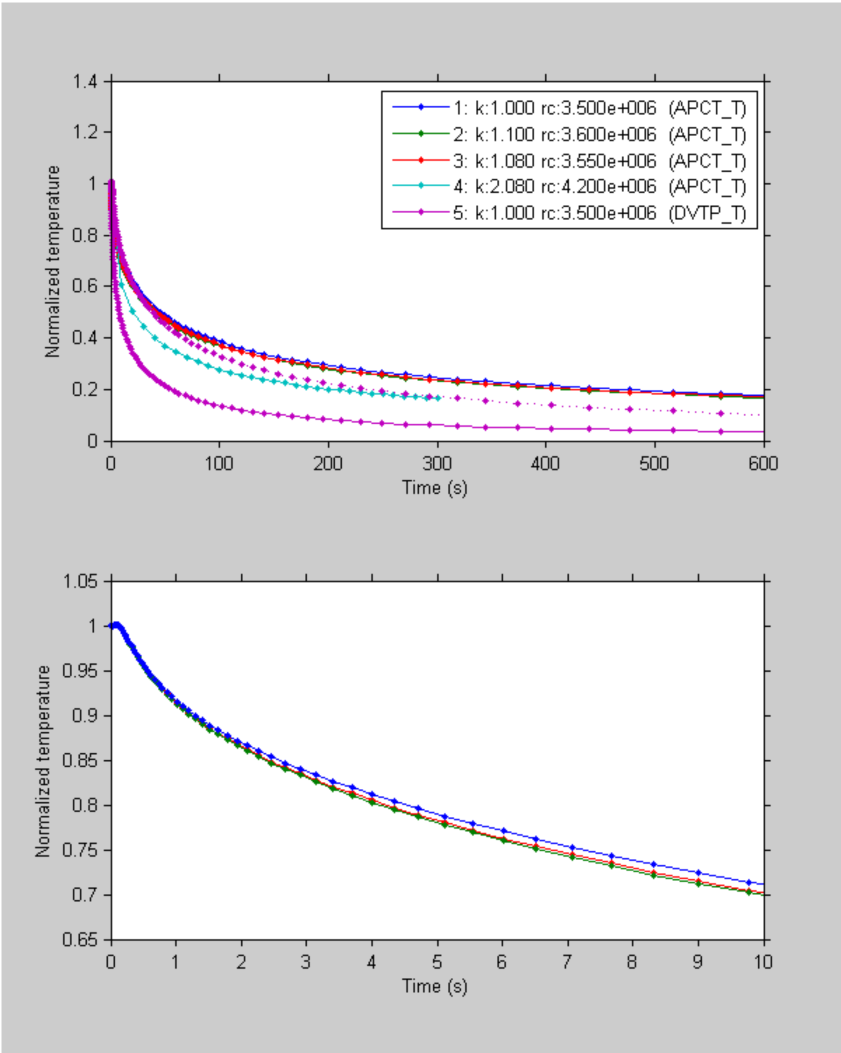
```
clf;
a1=subplot(2,1,1);
hold on;
N=length(RefData);
Colors=lines(N);
for i=1:N
  LStr{i}=sprintf('%d: k:%.3f rc:%.3e  (%s)\n',...
              i,RefData{i}.k,RefData{i}.rc,RefData{i}.ModelType);
  h(i)=plot(RefData{i}.t,RefData{i}.T,'.-','Color',Colors(i,:));
  if isfield(RefData{i},'T2')
    plot(RefData{i}.t,RefData{i}.T2,'.:','Color',Colors(i,:));
  end
end
xlabel('Time (s)');
ylabel('Normalized temperature');

AxesParams={'Box','on',...
  'TickDir','out'};
set(gca,'XLim',[0 10*60],AxesParams{:});
```

```
legend(h,LStr,'Interpreter','none');


a2=subplot(2,1,2);
copyobj(h(1:3),gca);
xlabel('Time (s)');
ylabel('Normalized temperature');
set(gca,'XLim',[0 10],AxesParams{:});
```

Figure 1-9. Author: Figure Caption?



1.6 Software Installation

In order to run TP-Fit, version 7.0 of Matlab® is required. The installation is as simple as unpacking the TP-Fit.zip file on your computer. A TP-Fit directory with three subdirectories is created.

- The doc directory contains the sources for this document.
- The MatLab™ directory contains all parts necessary to run the program
  - The TPFit.m, lauched within Matlab®, sets some paths and runs the TP-Fit graphical user interface.
  - The RefModels directory contains numerically computed reference curves (e.g. thermal response) for the supported downhole tools (currently APCT and DVTP). Further subdirectories contain the Femlab® models that where used to create the reference curves.
  - The TP-Fit directory contains Matlab® functions used for the actual data processing.
  - The TestData directory contains some example data sets of different downhole temperature probe types for testing purposes.

If you have any suggestions or make changes to the documentation or other files, please let me (heesema@uni-bremen.de Author: is this e-mail address still current?) know, so I can include the changes in upcoming releases.

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