Graphical User Interface for TOUGH/TOUGH2 - Development of Database, Pre-processor, and Post-processor

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Abstract

One of the advantages of the TOUGH/TOUGH2 (Pruess, 1987 and 1991) is the modeling using "free shape" polygonal blocks. However, the treatment of three-dimensional information, particularly for TOUGH/TOUGH2 is not easy because of the "free shape" polygonal blocks. Therefore, we have developed a database named "GEOBASE" and a pre/post-processor named "GEOGRAPH" for TOUGH/TOUGH2 on engineering work station (EWS).

"GEOBASE" is based on the ORACLE[*1] relational database manager system to access data sets of surface exploration (geology, geophysics, geochemistry, etc.), drilling (well trajectory, geological column, logging, etc.), well testing (production test, injection test, interference test, tracer test, etc.) and production/injection history.

"GEOGRAPH" consists of "Pre-processor" that can construct the three-dimensional free shape reservoir modeling by mouse operation on X-window and "Post-processor" that can display several kinds of two/three-dimensional maps and X-Y plots to compile data on "GEOBASE" and result of TOUGH/TOUGH2 calculation.

This paper shows concept of the systems and examples of utilization.

1. Introduction

Processes of geothermal reservoir simulation are as follows; 1) construction of the conceptual hydrothermal model, 2) design of the grid block model, 3) natural state simulation, 4) history matching simulation, and 5) reservoir performance prediction.

On series of the numerical modeling, we have a few hundred to a few thousand of three-dimensional grid blocks. Therefore, we encounter many problems such as are:

1) It takes much time to generate the free shape polygonal blocks. 2) Outputs of TOUGH/TOUGH2 data (ex. P, T, SG, etc.) and observation data of wells (ex. P, T) are three-dimensional data. Therefore, two-dimensional interpolation is not exactly correct and three-dimensional interpolation is essential correctly. 3) It is very difficult to compare the calculated results with observation data. 4) Periodical modification of reservoir model using new data set may be required. Then, it is necessary for adequate reservoir simulations to have the database for managing existing data and new data that will be gotten in future.

We have developed a pre-processor and a post-processor, and a database named "GEOGRAPH" and "GEOBASE" respectively. Using these systems, we are aiming to conduct geothermal simulations efficiently. In this paper, we introduce summary of our systems as shown in Figure 1.

We have developed these systems on HP9000/755 (HP-UX9.03). And we use UNIRAS[*2] and PV-WAVE[*3] for mapping applications, and ORACLE for database platform.

[*1]Product of the Oracle Corporation

[*2]Product of the UNIRAS

[*3]Product of the Visual Numerics Inc.

2. Pre-processor

"Pre-processor" can construct the three-dimensional numerical models for TOUGH/TOUGH2 by mouse operation on X-window (X11R5). Since the program is based on GKS, this code does not depend on hardware so much.

2.1 Grid blocks and rock type definition

We define the grid blocks on the screen in graphics mode (see Figure 2).

1) We define the first element of the XY-plane structure in our grid. Next, we divide it to small blocks.
2) We define the layout of the grid in the z direction. First, we define it to occupy the area between z=zmin and z=zmax. Next, we copy our grid into other layers.
3) We add some regions defining the different rock type over our grid each layer.
4) We define the well blocks.

On these processes, ELEME and CONNE are made, and well block for GENER is defined.

2.2 Boundary and initial condition

We define the boundary and initial condition on the screen in graphics mode.

1) We set temperature and pressure on the top, bottom and side faces for initial condition. Or we can set pressure and temperature along the column of water at boiling point. These values are used to interpolate P and T over the whole face.
2) We set the boundary rocks connecting top, bottom and side faces (if necessary).

On these processes, INCON is made and information of boundary blocks is added to the ELEME and CONNE.

2.3 Parameters

We define the parameters (ROCKS, PARAMS, RPCAP, TIMES, GENER, etc.) on the screen in no graphics mode.

2.4 Generating the TOUGH/TOUGH2 input file

After finishing the above 2.1 to 2.3 stage, we compile each data set and make the input files using the generating input file program. In this stage, a file containing block names and the x, y, z coordinates of the center of the blocks is made.

3. Post-processor

"Post-processor" can display several kinds of two/three-dimensional maps and X-Y plots to compile data on the database and the calculation results of TOUGH/TOUGH2.

3.1 Three-dimensional contouring

Output files of TOUGH/TOUGH2 include each time step information from start to end of calculation. On the post-processor, we can select the data set for required time step using key word that is "TOTAL TIME =". Since the selected time-step data of TOUGH/TOUGH2 output (ex. P, T, SG, etc.) and observation data of wells (ex. P, T) have three-dimensional coordinate system, the cross point of both contour maps of horizontal distribution and the cross section based on two-dimensional data are not coincident exactly (see Figure 3).

Therefore, we use three-dimensional krigging for making contour maps on horizontal plane and vertical plane. On this process, the TOUGH/TOUGH2 output and observation data are used to interpolate each value over three-dimensional regular grid for mapping. After this, we can draw contour maps of horizontal plane and vertical plane.

Figure 4a is the example of contour map for horizontal plane, showing mismatching (residual) value of temperature between calculation and observation. We can know the meaningful matching area of the map by compiling the well pass points on each layer from "GEOBASE" (near well bore). Figure 4b shows the example of contour map for vertical plane. On these figures, the cross point of two contours is interpolated correctly.

And we can draw the three-dimensional bench-cut distribution maps as Figure 5a.

3.2 Three-dimensional flow vector map

Selected data set on the above 3.1 include flow vector information (ex. FLOF, FLOH, etc.). In this stage, we can draw the three-dimensional flow vector map.

Firstly, we pick up the data (ex. FLOF, FLOH, etc.) from TOUGH/TOUGH2 output file. Next, flow vector on each grid block is calculated using CONNE, and plotted on the three-dimensional space.

3.3 x-y graph

On history matching simulation, we have to compare the TOUGH/TOUGH2 outputs with well testing and production/injection data.

Firstly, we select the well blocks. Next, we pick up the data set (ex. T, P, SG, SL, ENTHALPY, etc.) of all time steps. And, we draw calculated results and observation data on the x-y graph.

Figure 6 shows example of matching operation.

4. Database

The data used for construction of conceptual model and the data for matching are stored on database which is based on the ORACLE relational database manager system.

The following data are stored; 1) well depth versus observation data, 2) time versus observation data, 3) two- or three-dimensional coordinate versus observation data. For example, 1) are well trajectory and well log data, 2) are well test and production/injection data, and 3) are distribution of temperature, pressure and geophysical data.

Each data set has header information table and ID code. At first, we search the header table and get the ID code. Then, we get the data set using ID code. And we send the data set to post-processor (see Figure 1).

5. Summary

TOUGH/TOUGH2 is trusted for geothermal simulator. But, we know it is time consuming process to generate model and it is difficult to compare calculated results with observation data. Also, even two-dimensional contouring of the TOUGH/TOUGH2 outputs should be made with three-dimensional interpolation technique, theoretically.

Therefore, we have developed pre-processor, post-processor and database for TOUGH/TOUGH2. We have confirmed using this system that we can make models efficiently and exactly, in addition we can show the performance of reservoir visually.

Reference

Pruess, K., 1987, *TOUGH User's Guide*, Earth Sciences Division, Lawrence Berkeley Laboratory, Univ. of California.

Pruess, K., 1991, *TOUGH2 - A General Purpose Numerical Simulator for Multi Phase Fluid and Heat Flow*, Earth Sciences Division, Lawrence Berkeley Laboratory, Univ. of California.

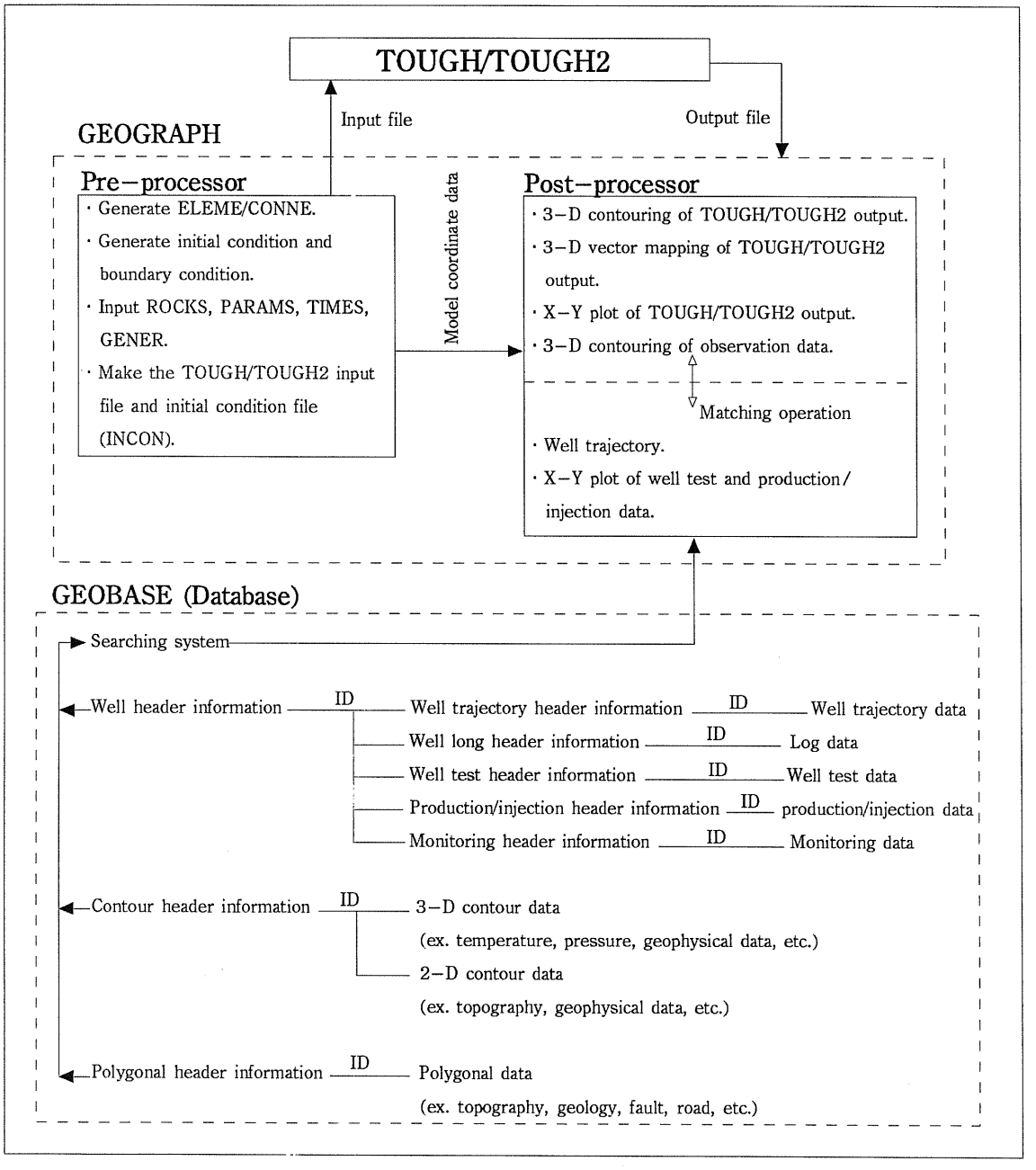

Figure 1. Summary of GEOGRAPH (pre/post−processor) and GEOBASE (database) for TOUGH/TOUGH2.

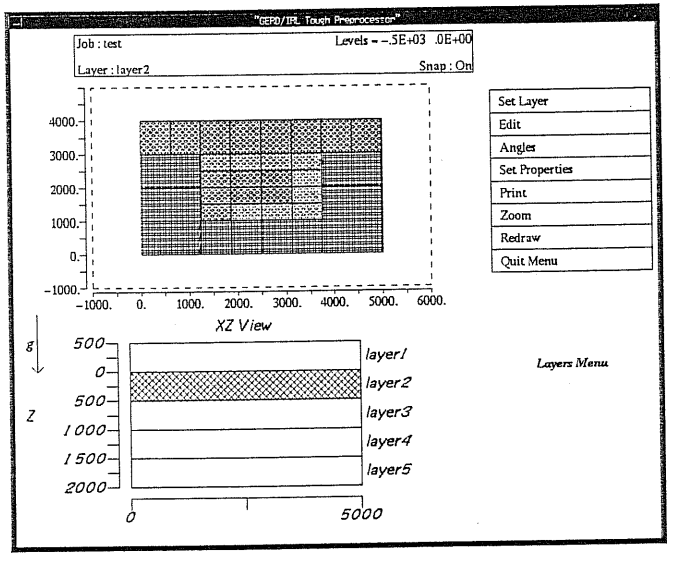

Figure 2. Example of grid blocks and rock type definition on pre-processor.

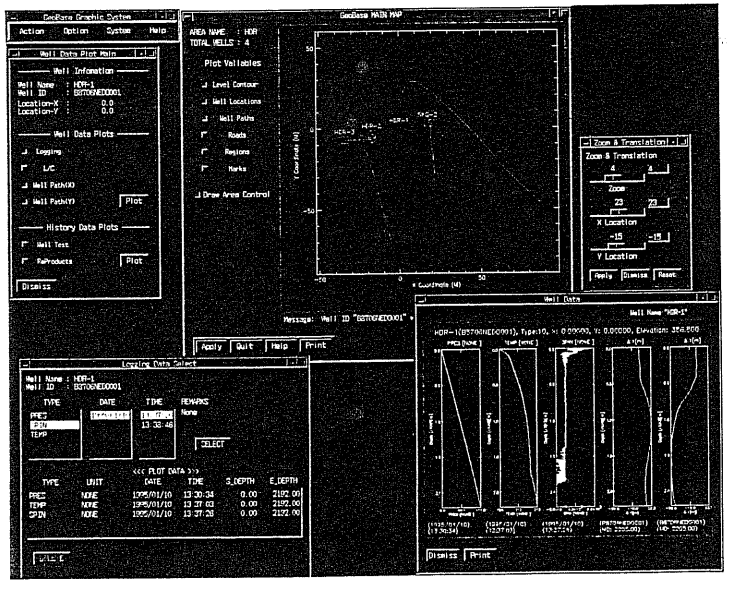

Figure 6. Example of database operation. The display shows searching well log data.

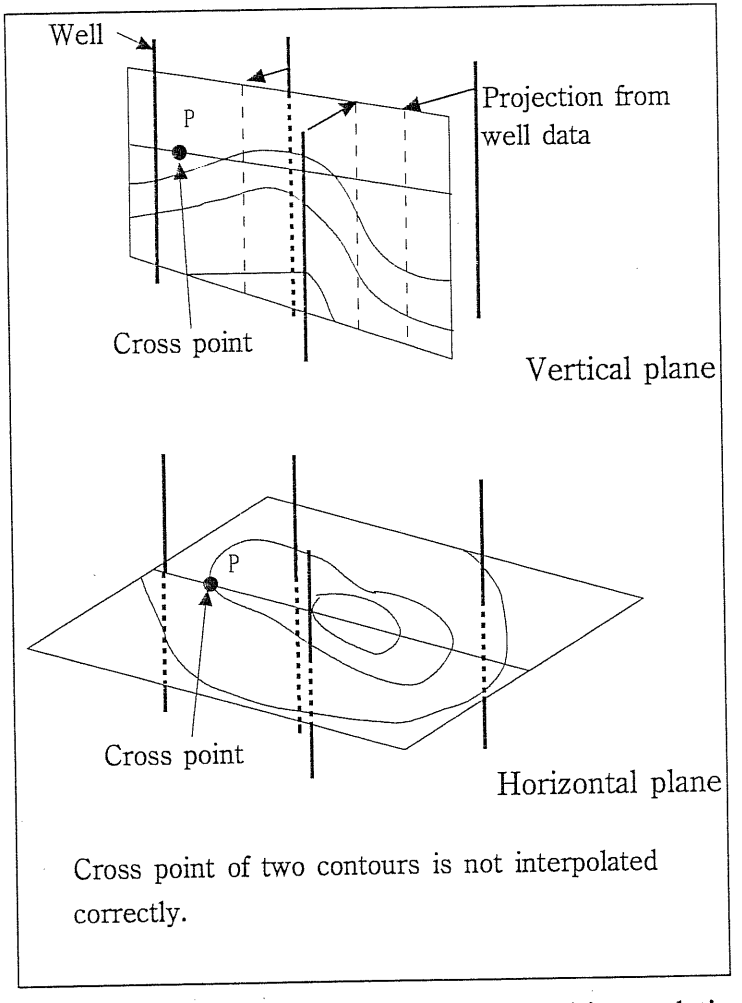

Figure 3. Mismatching of two-dimensional interpolation using three-dimensional data.

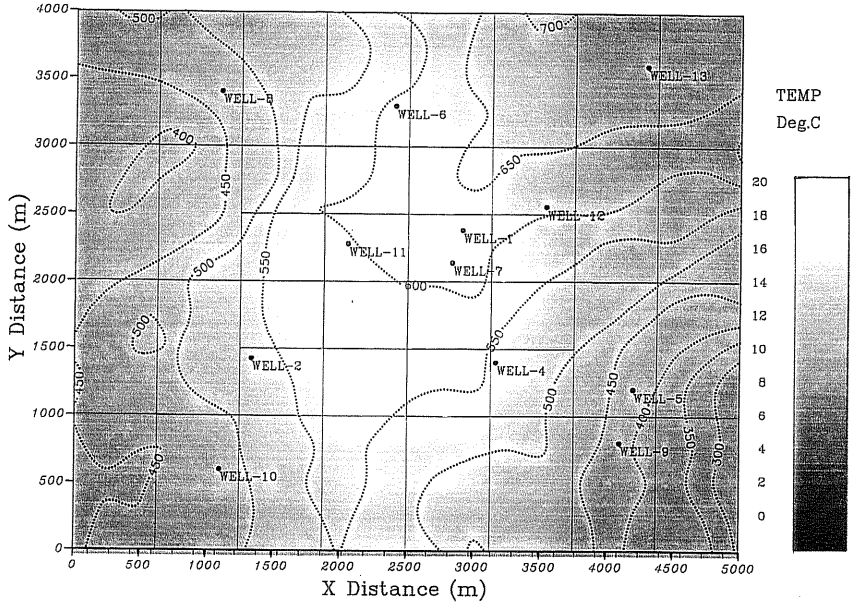

Figure 4a. Example of post-processor contour map (horizontal plane). The contour shows mismatching (residual) value of temperature between calculation and observation.

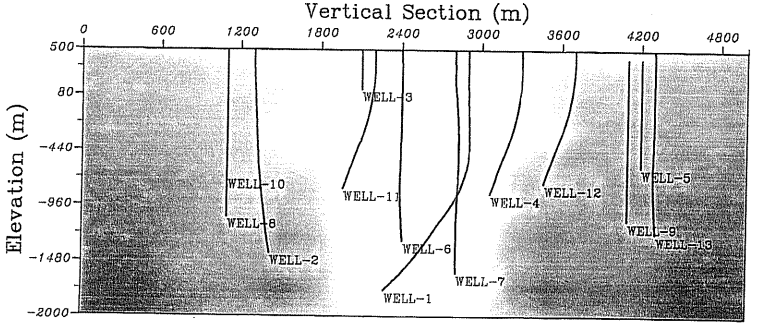

Figure 4b. Example of post-processor contour map (vertical plane). The contour shows mismatching (residual) value of temperature between calculation and observation.

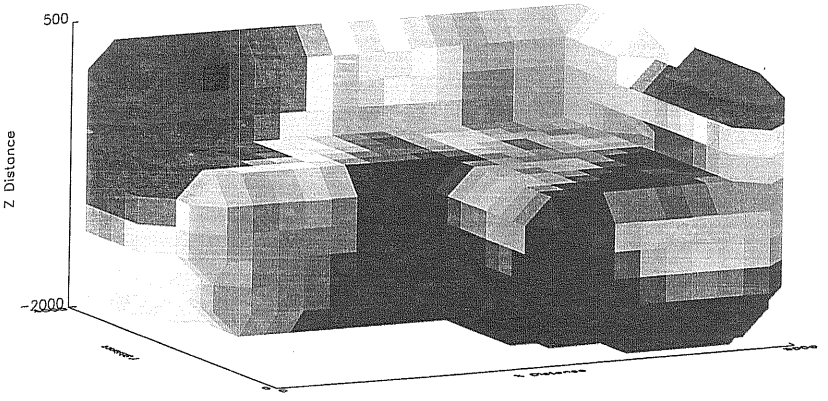

Figure 5a. Example of three-dimensional block map. The block map shows the three-dimensional bench-cut distribution of temperature.

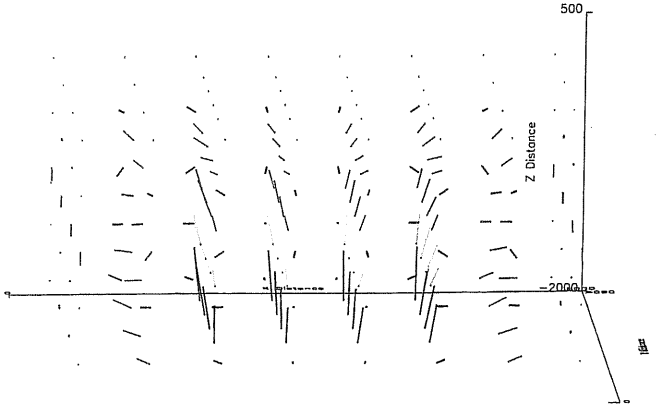

Figure 5b. Example of three-dimensional vector map. The vector map shows fluid flow vector of TOUGH/ TOUGH2 output.