Development of an Integrated Geothermal Reservoir Modeling System for the Modeling Study using TOUGH2

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ABSTRACT

We developed the integrated geothermal reservoir modeling system on PC (Windows95/NT) or UNIX that can combine database, pre-processor and post-processor for the modeling study using TOUGH2. The system consists of;

(1) Exploration and production database system including the mapping system: GEOBASE2.3.
(2) Pre-Processor : GeoCAD3.0 for constructing a three-dimensional grid model for TOUGH2.
(3) TOUGH2.
(4) Post-Processor for calculation of the micro-gravity change : GRAV/TOUGH2 We here by introduce the performance of the system using Yanaizu-Nishiyama geothermal field data. (Okuaizu Geothermal Co., Fukushima prefecture, Japan).

INTRODUCTION

Geothermal reservoir modeling and the prediction of geothermal production behavior using numerical simulation based on geothermal reservoir modeling are important steps towards the construction of a geothermal power station. In geothermal reservoir modeling it is necessary to combine surface exploration results and well data obtained from various survey stages of rough to detailed examination in order to form an integrated three-dimensional model of a geothermal reservoir. Since exploration data have been collected by many researchers in the fields of geology, geophysics, chemistry, drilling, logging, reservoir engineering, etc., over a long period of time, specialists in geology and reservoir engineering must make a great effort to find information essential for geothermal reservoir modeling out of a tremendous amount of data presented in various formats. Given this situation, construction of a consistent three-dimensional stereoscopic model is a time-consuming job requiring much skill if it is to be done in a human's head. Also, in forming a numerical model grid for ultimate numerical modeling simulation, a considerable amount of time is required to improve the accuracy of modeling because numerical modeling is also time-consuming and requires much skill. Therefore "computer-aided comprehensive analytic techniques" for geothermal reservoir modeling which use the latest in computer technology are becoming popular (Anderson et al., 1995; Stevens et al., 1995; Nakanishi et al.,1997).

In many geothermal power stations flow data from a specific well, or even from a specific flash separator connected multiple wells in extreme cases, are mostly used for production history matching.

This report describes application of the integrated geothermal reservoir modeling system developed in the present study, which uses an exploration and production database, a pre-processor for designing of a reservoir model, TOUGH 2 (Pruess, 1991), and a post-processor for micro-gravity, to the Yanaizu-Nishiyama geothermal field.

BACKGROUND

The Yanaizu-Nishiyama Geothermal Power Station, located in Yanaizu-cho in Fukushima Prefecture, is a single-unit geothermal power station with the largest steam turbine (of the single-flush type) in Japan, with an approved capacity 65MW. Tohoku Electric Power Company is responsible for the power generation section of the station, and Okuaizu Geothermal Co. is responsible for the steam supply section. The station began operation in May 1995.

Okuaizu Geothermal Co., which is in charge of development of the station and management of the steam production facilities, started computer control of production-injection data immediately after the start of operation. Also, it has been selecting data required for future reservoir control, developing an exploration and production database using GEOBASE (Sato et al., 1995) developed by the authors (K. Osato and T. Sato) and the pre-processor to be used for TOUGH2, and reviewing the production behavior which was predicted using the numerical geothermal reservoir model and TOUGH 2 in 1996.

This paper describes the construction of the database and utilization for numerical simulation of Yanaizu-Nishiyama geothermal field.

OUTLINE OF THE SYSTEM

The system consists of:

(1) Exploration and Production database system GEOBASE2.3 for entering, querying, and displaying all the types of data in a comprehensive manner

(2) Pre-processor GeoCAD3.0 for constructing a three-dimensional numerical model based on the conceptual model obtained by integrated data analysis from the database

(3) Reservoir simulator TOUGH2.

GEOBASE2.3 runs on UNIX (HP9000/700, SUN) or PC (Windows95/NT). GeoCAD3.0 runs on UNIX (HP 9000/700) or PC (Windows95/NT).

The database is based on Oracle (the current version is Oracle 7.2 or Personal Oracle 7.2), a decentralized relational database which is popular all over the world. The database has a simple structure, and it is possible to redefine and enter all types of data which can be fitted in the structure into the database. If Oracle 7.2 is used, it is also possible to form a decentralized system (client-server system) using a LAN or WAN which can easily join PCs and UNIX machines. The retrieval and mapping function of the database allows a two-dimensional or three-dimensional representation of data to be obtained by using single data sets or superimposing various data sets, e.g., geological column diagrams, logging data, surface survey data, production/injection data, results of reservoir simulation. Figure 1 shows the data structure.

CONSTRUCTION OF A NUMERICAL MODEL USING THE DATABASE AND THE PRE-PROCESSOR

Figure 2 shows the underground temperature distribution 1,500 m below sea level constructed using the database, the lost-circulation points, the feed points of production wells obtained by PTS logging, and the fault distribution at 1,200 m below sea level. Figure 3 shows the NE-SW cross-sectional view onto which corresponding geological column diagrams are projected.

High temperature zone exist along the NW-SE fault on south -west side (See Figure 2). Many feed points (Filled circle in Figure.2 and 3) exist along this fault and it is major production zone in this field. Reinjection zone is along NW-SE fault on north-east side. Few feed points exist along it.

In the numerical model, the NE-SW length of the area was taken to be 4.6 km so that the fault directions can be taken into consideration and the high temperature range can be covered. The NW-SE length was taken to be 3.2 km. As for the internal grid, the area near the faults relating to production and injection was divided into smaller blocks and the surrounding area was divided into larger blocks. The first layer of this model was taken to be the range between the surface level, which is about 500 m above sea level. The range from sea level down to -2,000 m below sea level was divided into 300 - 500 m layers. As boundary conditions, the pressure and temperature on the ground surface was assumed to be constant, and closed boundaries were assumed on the side faces of the model. To reconstruct the underground temperature distribution, two recharge blocks were placed on the south side of each of the first to third layers, and one recharge block was placed to the west of the second layer. EOS2 (H2O-CO2) of TOUGH2 was used as the state equation to take the CO2 of geothermal fluid into consideration.

In actual modeling, the pre-processor GeoCAD3.0 that had been developed by the authors (J. Burnell and S. White) was used. Since GeoCAD3.0 can readily form non-uniform (polygonal) grids taking advantage of the IFDM of TOUGH2, input data for TOUGH2 can be prepared by drawing quadrilaterals and polygons using a mouse and indicating the necessary physical properties in the center of each polygon. In this case, general rectangular grid division was made horizontally, and grid division in accordance with the inclination of the faults was made vertically. Figure 4 shows the sample display of GEOCAD3.0.

STEADY-STATE MODELING BY MEANS OF NUMERICAL SIMULATION

Since the numerical simulation was done just before the start of operation of the station, the model was optimized according to the steady-state. However, review of the numerical model based on the production history after the start of operation has not been done. The numerical model was constructed based on the base model used in the 1989 reservoir evaluation taking data from new wells into consideration. Figure 6 shows the underground temperature distribution calculated using the steady-state-optimized numerical simulation, the actual underground temperature distribution (both at 1,500 m below sea level) with the grids of the fourth layer designed by GEOCAD3.0. Figure 6 shows the NW-SE cross-sectional view of Figure5.

CONCLUSIONS

It was proven that a integrated geothermal reservoir modeling system using a exploration and production database, a pre-processor for reservoir modeling, a reservoir simulator, and a post-processor for micro-gravity can be effectively used in the whole course of modeling, numerical modeling, numerical simulation, and evaluation using production history.

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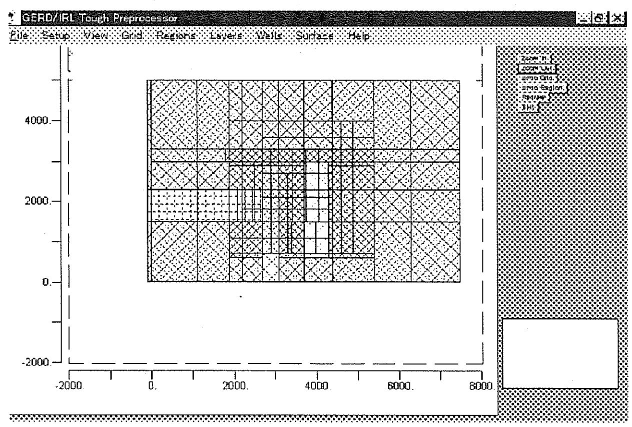

Figure 4. A sample display of GEOCAD3.0 on PC.

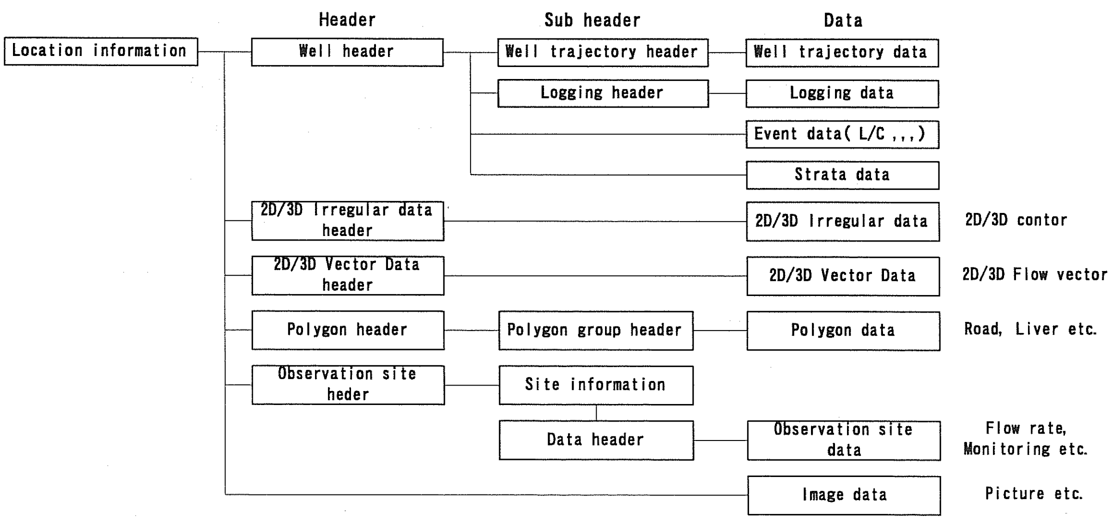

Figure 1. Data Table Structure of GEOBASE

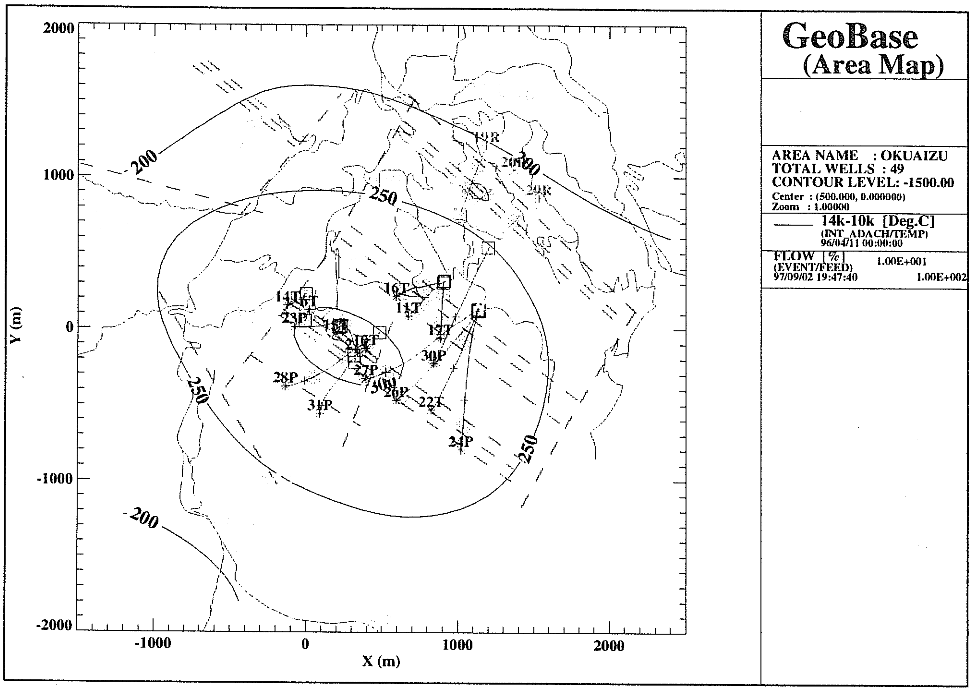

Figure 2. Underground temperature distribution (1,500 m below sea level) constructed from the database, lost-circulation points, feed points of production wells, and fault distribution (1,200 m below sea level)

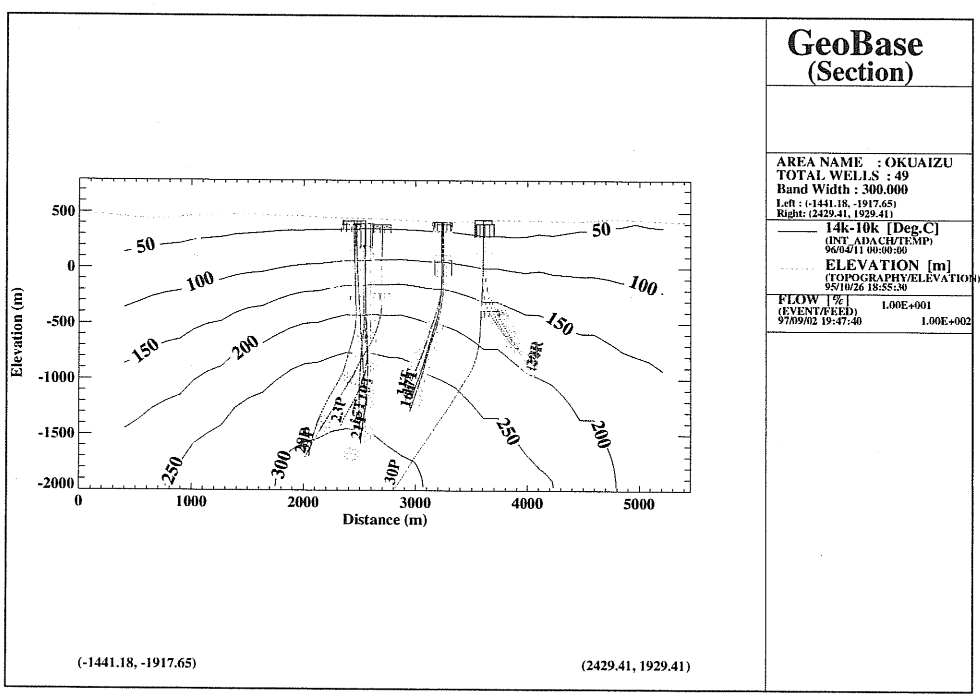

Figure 3. NE-SW Cross-sectional view of the underground temperature distribution, lost-circulation points, feed points of production wells, and projected geological columns

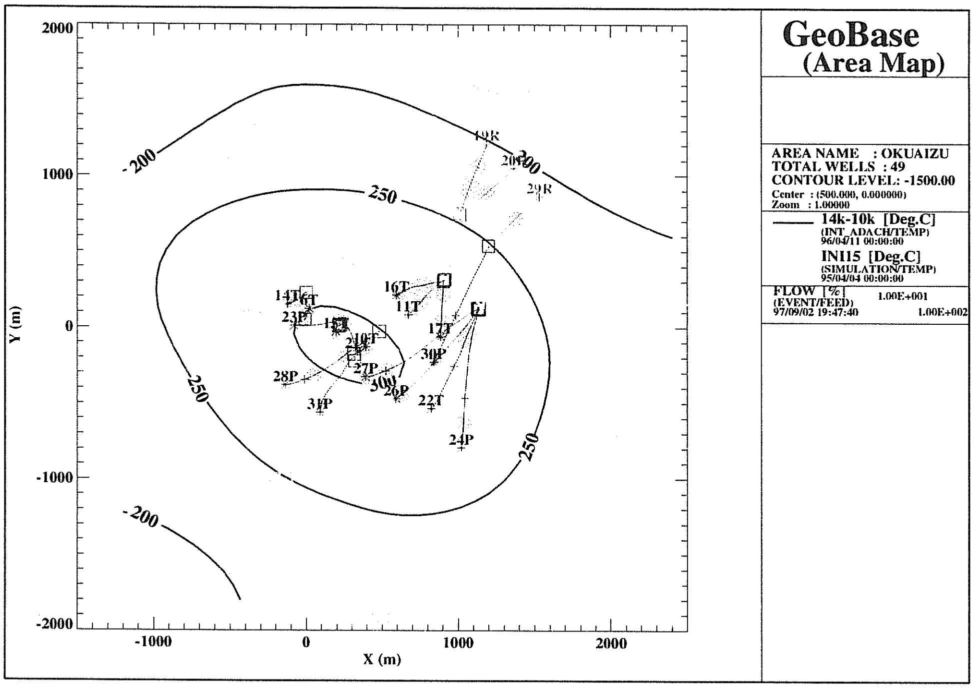

Figure 5. Underground temperature distribution optimized by steady-state modeling (dash line), and the actual underground temperature distribution with grids of the fourth layer designed by GEOCAD3.0

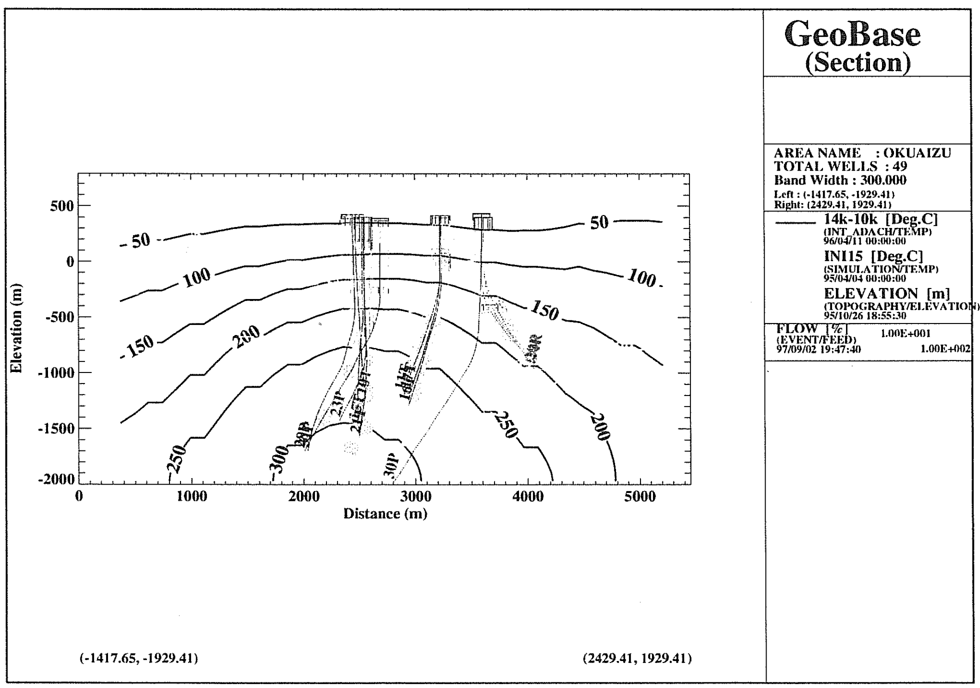

Figure 6 NE-SW cross-sectional view of the underground temperature distribution optimized by steady-state modeling(dash line), and the actual underground temperature distribution at 1,500 m below sea level