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DEVELOPMENT OF AN INTEGRATED GEOTHERMAL RESERVOIR MODELLING SYSTEM AND ITS APPLICATION TO THE OKUAIZU GEOTHERMAL FIELD

T. NAKAO[1], T. SATO[1], T. OKABE[1], S. WHITE[2],
J. BURNELL[2] AND S. YOKOMOTO[3]

Geothermal Energy Research & Development Co. Ltd. Tokyo, Japan
Industrial Research Limited, Lower Hutt, NZ
Okuaizu Geothermal Co. Ltd., Tokyo, Japan

SUMMARY - We have constructed a new way of integrating a geothermal reservoir modeling system on PC (Windows9X/NT) and UNIX that includes a database, a pre-processor and a post-processor forthe TOUGH2 reservoir simulator. The system consists *of;*

(1) Exploration and production database system including a mapping system: GEOBASE2.4
(2) Pre-Processor : GeoCAD3.0 for constructing a 3-dimensional grid model for TOUGH2
(3) Numerical reservoir simulator : TOUGH2
(4) Post-Processor for the calculation of the micro-gravity change : GRAV/TOUGH2
(5) The WWW server system for "GEOBASE2.4" that helps use in a network environment : Geo-Surf

We introduce performance and special features (collaborated environment, VRML output) of the system by using Yanaizu-Nishiyama geothermal field data.

1. INTRODUCTION

Geothermal reservoir modeling and prediction of geothermal production behavior are important steps for construction of a geothermal power station. In geothermal reservoir modeling, it is necessary to combine surface exploration results and well data in order to form an integrated 3-dimensional model of a geotheml reservoir. Exploration data have been collected by many researchers in the fields of geology, geophysics, chemistry, drilling, logging, etc., over a long period of time. Specialists in geology and reservoir engineering take great effort to find information which is essential for the geothermal reservoir modeling out of a tremendous amount of data that exists in various formats. Construction of a consistent, 3-dimensional stereoscopic model based on the information is a time-consuming job. It also takes time to produce a 3-dimensional numerical model which requires appropriate grid structures, physical rock properties, boundary conditions and so on. Recently, "computer-aided comprehensive analytic techniques" for geothermal reservoir modeling are becoming popular (Anderson et al., 1995; Stevens et al., 1995; Nakanishi et al., 1997).

This paper describes an application of an integrated geothermal reservoir modeling system, which is applied in the study of the Yanaizu-Nishiyama geothermal field. The system consists of an exploration and production database, a pre-processor for designing a reservoir model and TOUGH2 (Pruess, 1991).

2. BACKGROUND

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

Okuaizu Geothermal Company, which is in charge of the 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 by using GEOBASE (Sato et al, 1995) that had been developed by GERD in 1995, and reviewing the production behavior which was predicted using TOUGH2. The numerical model for TOUGH2 was produced by using a pre-processor GeoCAD. We have been developing an integrated database system by using Ynaizu-Nishiyama geothermal field data.

3. OUTLINE OF THE SYSTEM

The system consists of:

(1) Exploration and Production database system GEOBASE2.4 for entering, querying, and

displaying all the types of data in a comprehensive manner (see Figure 1).

(2) Pre-processor GeoCAD3.0 for constructing a 3-dimensional numerical model based on a conceptual model obtained by integrated data analysis.

(3) Reservoir simulator TOUGH2.

(4) WWW (World Wide Web) system Geo-Surf.

GEOBASE2.4 runs on PC (Windows9X/NT) and UNIX (HP9000/700, SUN). GeoCAD3.0 runs on PC (Windows9X/NT) and UNIX (HP 9000/700) . Geo-Surf runs on PC (Windows 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 into the database structure. 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 2 and 3-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, productiodinjection data, results of reservoir simulation. Figure 1 shows an example display fiom GEOBASE2.4. Figure 2 shows data structure of GEOBASE2.4. In the following section, we show how we apply the system to the Yanaizu-Nishiyama field.

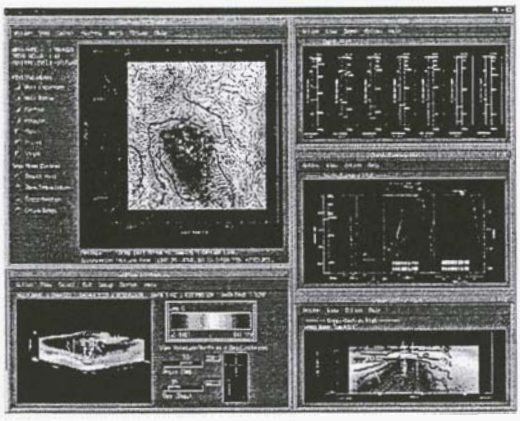

Figure 1. Overview of GEOBASE2.4.

4. CONSTRUCTION OF A NUMERICAL MODEL BY USING GEOBASE2.4 AND GeoCAD3.0

Figure 3 shows an underground temperature distribution 1,500 m below sea level constructed by using GEOBASE2.4 based on temperature logs. Lost-circulation points, feed points of production wells obtained by PTS logging, and fault distribution at 1,200 m below sea level are displayed. Figure 4 shows a NE-SW cross-sectional view .onto which corresponding geological column diagrams are projected.

A high temperature zone exists along the NW-SE fault on south -west side (See Figure 3). Many feed points (Solid circles in Figures 3 and 4) exist along this fault and it is a major production zone in this field. The 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 top of the first layer of this model is bounded by the surface level, which is about 500 m above sea level. The zone from sea level down to -2,000 m below sea level was divided into 300 - 500 m layers. As boundary conditions, pressure and temperature on the ground surface were 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 three layers, and one recharge block was placed to the west of the second layer. The state equation EOS2 (H_2O-CO_2) in TOUGH2 was used because of high CO_2 gas concentration.

In modeling, the pre-processor GeoCAD3.0 that had been developed by J. Burnell, S. White and GERD in 1990 was used. Since GeoCAD3.0 can readily form non-uniform (polygonal) grids taking advantage of the IFDM (Integrated Finite Difference Method) 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 grids were used in the area (Figure 5) and vertical faults were modeled by using small *grids* with depth.

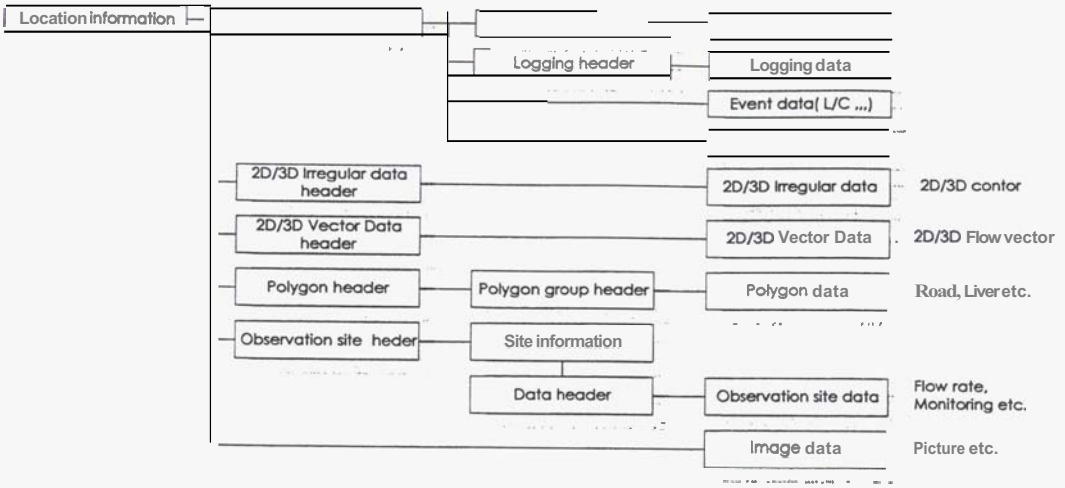

Figure 2. Data Table Structure of **GEOBASE2.4.**

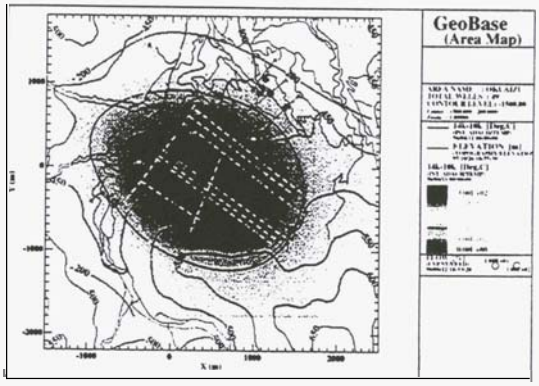

Figure 3. Underground temperature distribution (1,500m below sea level) constructed from **GEOBASE2.4,** lost-circulation points, feed points of production well and fault distribution.

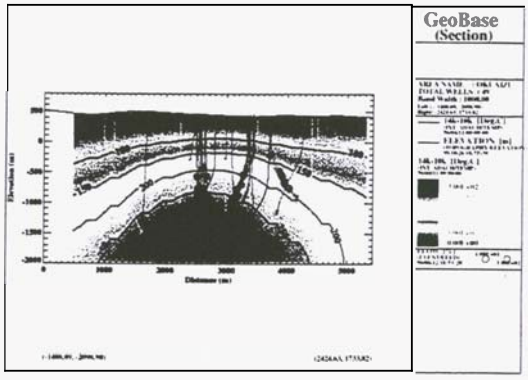

Figure 4. **NE-EW** cross sectional view of the underground temperature distribution, lost-circulation points, feed points of production wells.

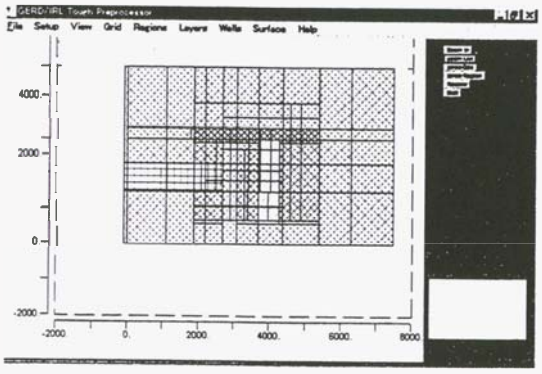

Figure 5. A sample display of GeoCAD3.0 on PC.

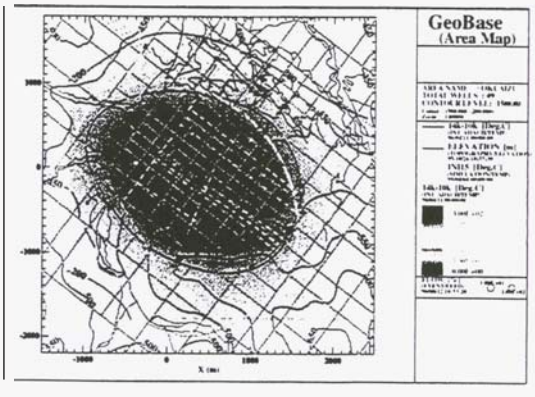

Figure 6. A comparison between an underground temperature distribution optimized by steady state modeling (gray line), and the actual underground temperature distribution.

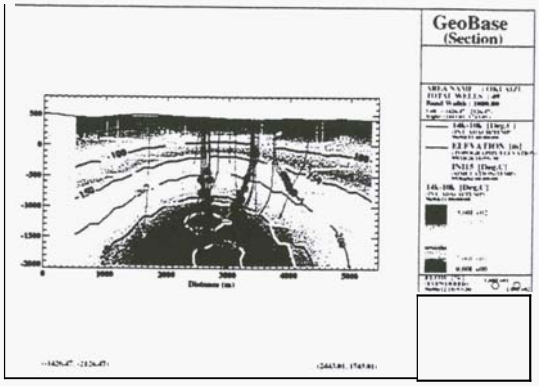

Figure 7. A comparison between an underground temperature distribution optimized by steady state modeling (gray line) and actual underground temperature distribution at 1,500m below sea level. NE-SW cross sectional view.

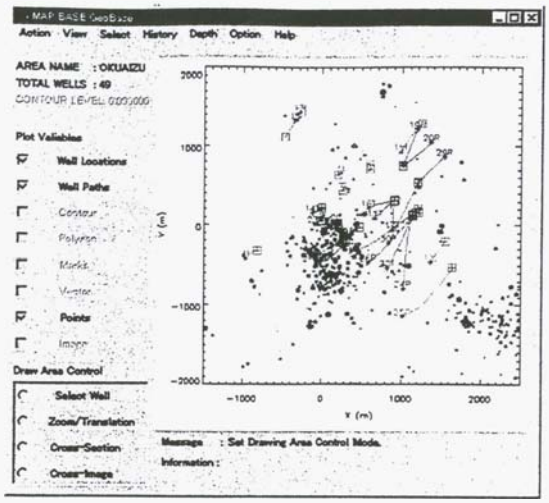

Figure 8. A ground plan view of well trajectories.

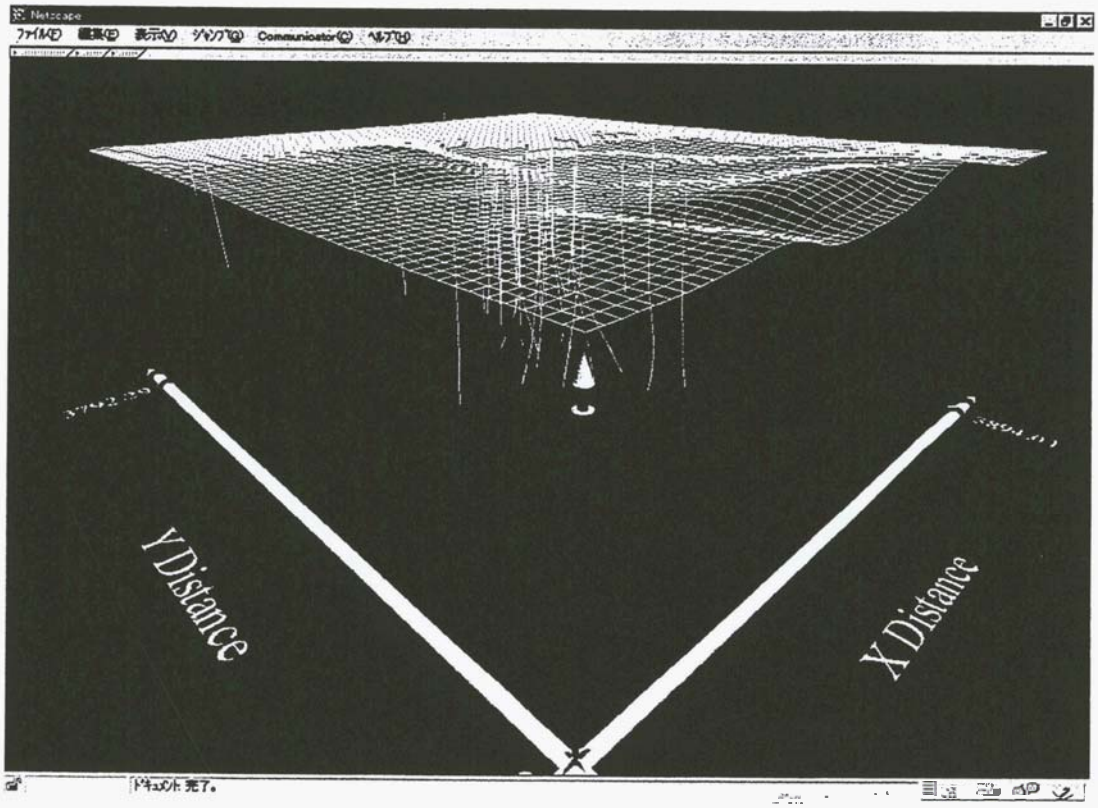

Figure 9. A 3-dimensional view of well trajectories (VRML).

5. RESULTS OF STEADY-SIMULATION

Since the numerical simulation was done just before the start of operation of the power plant, the model was optimized to match the steady-state. A 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 an existing model with additional information from wells in 1989. Figure 6 shows a comparison between an underground temperature distribution calculated using the result of the optimized steady-state simulation and the actual underground temperature distribution (at 1,500 m below sea level). Figure 7 shows NW-SE cross-sectional view of Figure 6. We can readily see how the calculation result and the field data are matched with each other by using the present system.

6. COLLABORATION BETWEEN A HEAD AND A BRANCH OFFICE

Okuaizu Geothermal Company has a head office in Tokyo and a branch in Nishiyama. They use GEOBASE2.4 in the head office. People in the head office require branch staff to search and pigeonhole the data and make graphs. They discuss the data and graphs with each other via e-mail, fax and phone. This can be time consuming because it is difficult to describe 2D and 3D images to another person (see Figures 8 & 9). VRML (Virtual Reality Modeling Language) is becoming popular and provides a solution to this problem (see Figure 9). With VRML it is easy to construct 3D images which may be viewed using a web browser such as Netscape Navigator. We have developed such a function called Geo-Surf which manages image files by using VRML and WWW. The communication and discussion between head and branch officed will enhance the development and management of the geothermal power station.

7. CONCLUSIONS

We developed a new integrated geothermal. reservoir modeling system on PC (Windows9X/NT) and UNIX. The system consists of a database (GEOBASE2.4), a pre-processor (GeoCAD3.0), a numerical reservoir simulator TOUGH2, a post-processor (GRAV/TOUGH2) and WWW server system (Geo-Surf). It was proven that the present system can be effectively used in the whole course of modeling, numerical modeling, numerical simulation, and evaluation by using the production history obtained through the study of the Yanaizu-Nishiyama geothermal field. Th network system and the new Internet technology (WWW, VRML) have provided a pathway for enhanced communication leading to increased efficiency in the development of a geotheml power station.

8. REFERENCES

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