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AN OVERVIEW OF THE PROJECT FOR EVALUATING DEEP-SEATED GEOTHERMAL RESOURCES IN JAPAN

Kazuo Koide[1], Tatsuya Sato[2], Hiroyuki Tokita[3], Takao Yamauchi[1], and Toshiyuki Tosha[1]

[1]New Energy and Industrial Technology Development Organization (NEDO)
1-1, Higashi-Ikebukuro 3-chome, Toshima-ku
Tokyo 170-6028, Japan
koidekzo@nedo.go.jp, yamauchitko@nedo.go.jp, tosyatsy@nedo.go.jp

[2]Geothermal Energy Research & Development Co., Ltd.
11-7, Kabuto-cho, Nihonbashi, Chuo-ku
Tokyo 103-0026, Japan
tatuya@gerd.co.jp

[3]West Japan Engineering Consultants, Inc.
Denki Bldg., Annex 5F, 1-82, Watanabe-dori 2-chome, Chuo-ku
Fukuoka 810-0004, Japan
tokita@wjec.co.jp

ABSTRACT

NEDO has been carrying out a project of evaluating the potentials of the deep-seated geothermal resources in Japan with several parameters such as temperature and permeability, which have been estimated using several kinds of stochastic methods and/or numerical reservoir simulation. The objective is to establish basic strategy for developing deep-seated geothermal resources in Japan. After finalizing the studies in the Kakkonda geothermal field, where the deep reservoirs is formed around the intrusive rocks, we have stated detailed studies on the deep-seated geothermal resources at the other Japanese fields have since 1999, choosing two model fields, the Uenotai (Tohoku area, northern part of Japan) and the Otake-Hatchobaru geothermal fields (Kyushu area, southern part of Japan). The reservoirs at the both fields are recognized as highly fault-controlled systems, a typical geothermal system in Japan. In addition, the Sumikawa-Onuma geothermal field in Tohoku area and the Ogiri geothermal field in Kyushu area are being studied in order to discuss the reliability of the estimation by the stochastic analysis and numerical simulation. Furthermore, databases of reservoir parameters such as temperature, pressure and permeability have been developed for the major geothermal fields in Japan including the above-mentioned fields, which helps us to not only utilize the stochastic methods but also construct the reliable numerical models.

INTRODUCTION

The main study areas in the Deep-seated Geothermal Resources Survey project as a part of the New Sunshine Program of MITI are shown in Figure 1. The project was conducted in the Kakkonda geothermal field from 1992 to 1998 and focused on the evaluation of the geothermal resources of the Uenotai and Otake-Hatchobaru geothermal fields from 1999 to 2000. In addition, we are currently evaluating the geothermal resources of the Sumikawa-Onuma and Ogiri geothermal fields. The results of these studies will be incorporated into the guidelines for the development of the deep-seated geothermal resources in Japan. This project will be completed at the end of March 2001.

In the Kakkonda area the studies including the drilling of a deep exploration well, which was drilled to a total depth of 3,729 m, were conducted for understanding of the entire Kakkonda geothermal system. Both stochastic analyses and numerical simulation have been applied to the Uenotai, Sumikawa-Onuma, Otake-Hatchobaru and Ogiri areas in order to determine the deep reservoir parameters for evaluation of deep-seated geothermal reservoirs. In addition, the approach using stochastic methods are being applied to the Mori (Hokkaido), Onikobe and Yanaizu-Nishiyama (Tohoku), and Takigami and Yamagawa (Kyushu) areas.

In this paper we give an overview of the results of the deep-seated geothermal resources evaluation of the Uenotai and Otake-Hatchobaru areas. We also present a scheme of the construction of guidelines for the development of deep-seated geothermal resources.

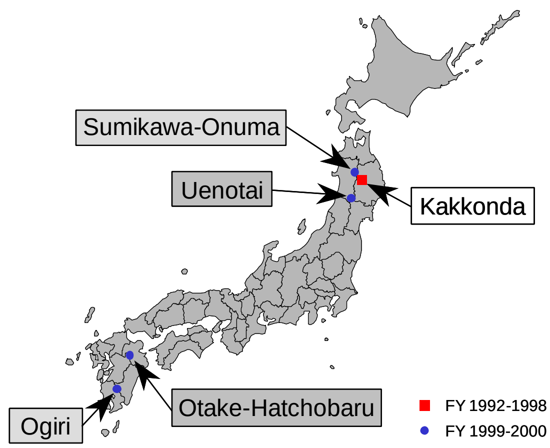

Figure 1. Study areas.

PROCEDURE FOR EVALUATION OF DEEP-SEATED GEOTHERMAL RESOURCES

Two approaches are used for the estimation of deep geothermal reservoir parameters: stochastic analyses and numerical simulation.

Stochastic methods were employed for the estimation of the parameters such as temperature, pressure and permeability in the deep subsurface. Different methods and techniques were tentatively apply to each area for better estimation of the parameters.

Numerical simulations by using the simulator TOUGH2 were carried out in order to assure the validity of the conceptual models and to estimate deep subsurface parameters in the Uenotai and Otake-Hatchobaru areas.

Based on the above two approaches, we built simple numerical models for each area and calculated the deep-seated geothermal resources.

UENOTAI FIELD

The Uenotai geothermal field is located in northeast Japan (Figure 1). The electric power station started to operate commercially in March 1994. There are 12 active wells in the Uenotai field as of March 2000: 8 are production wells and 4 are reinjection wells.

In this area pre-Tertiary basement rocks, Neogene and Quaternary formations, and intrusive rocks are widely distributed. Pre-Tertiary basement rocks consist of various types of rocks such as greenschist, serpentinite and granodiorite. The Neogene formations are divided into the Doroyu, Otoriyazawa, Minasegawa and Sanzugawa formations in ascending order. The Otoriyazawa formation has not been recognized at the surface, and is considered to be distributed locally in the subsurface. Quaternary formations are divided into the Kabutoyama formation and the Takamatsu-dake volcanic rocks. Intrusive rocks consist of granite, dacite, andesite and dolerite revealing formation during the Neogene age.

Stochastic Analyses

Detailed discussions on the estimation of the deep subsurface temperature distributions were made by Shiga et al. (2000). Two extrapolation methods and the relaxation method have been applied to the estimation of the temperature distributions at the deep layers. A extrapolation method (Method 1; Okubo et al., 1998), extrapolates the temperature gradients of the wells simply determined by those at the surface and bottomhole of the well. Another extrapolation method (Method 2) uses the temperature gradient of an interval of about 50-m interval near the bottomhole. Figure 2 shows two methods to estimate the deeper temperature.

The relaxation method (Tamanyu et al., 1995; 1996), for deep subsurface temperature distributions was useful in this area. The relaxation method was as follows; 1) temperature distribution map at the shallow reservoir was generated by the temperature profiles of the wells, 2) temperatures at a depth of 5,000 m below sea level were calculated using the extrapolation method (Method 2), and 3) using the shallower and deeper temperature profiles estimated at the steps of 1)

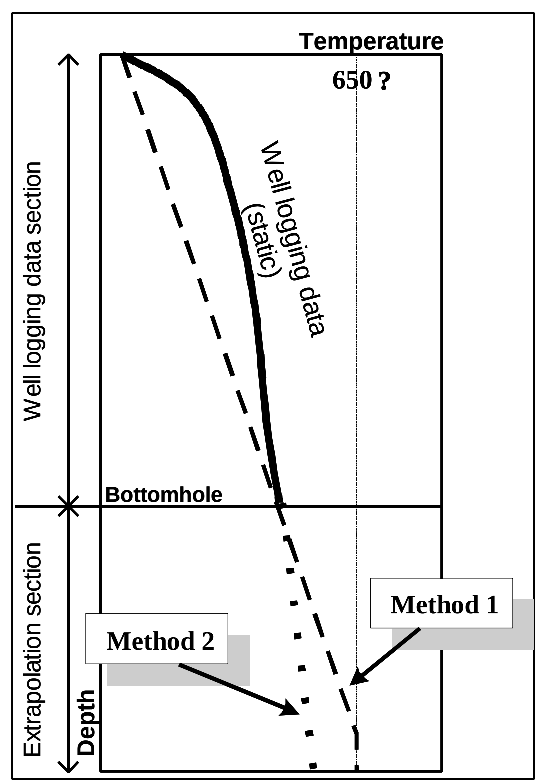

Figure 2. Comparison of temperature estimation methods (modified after Shiga et al., 2000).

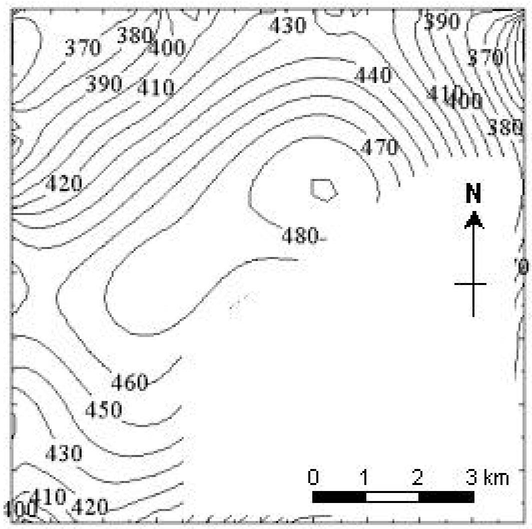

Figure 3. Temperature distribution at 4,000 m below sea level in the Uenotai area estimated using the relaxation method (modified after Shiga et al., 2000).

and 2), we can interpolate the temperature at any depth between the surface and a depth of 5,000 m below sea level by the relaxation method shown in Figure 3.shown in Figure 3.

The estimation of permeability in the deep subsurface was made by the steps as follows. We at first estimate the porosity of the rocks against the depth using core analysis data and the permeability using the relationship between the porosity and permeability. Finally we can guess at the permeability at any depth.

We also attempted to calculate permeabilities from velocities of convective ascending flow by using the temperature log data.

Conceptual Model

Plan view of a conceptual model of the Uenotai geothermal system is shown in Figure 4. The model covers not only the Uenotai area but also the Wasabizawa and Akinomiya areas, both are prospective geothermal areas, located about 4 km and 7 km southwest of the Uenotai geothermal field, respectively. The existing reservoir, at shallower than a depth of 2,000 m below sea level, is a fracture-controlled type, and fractures are developed mainly (1) around the boundary between pre-Tertiary basement rocks and the overlying Doroyu formation, and (2)

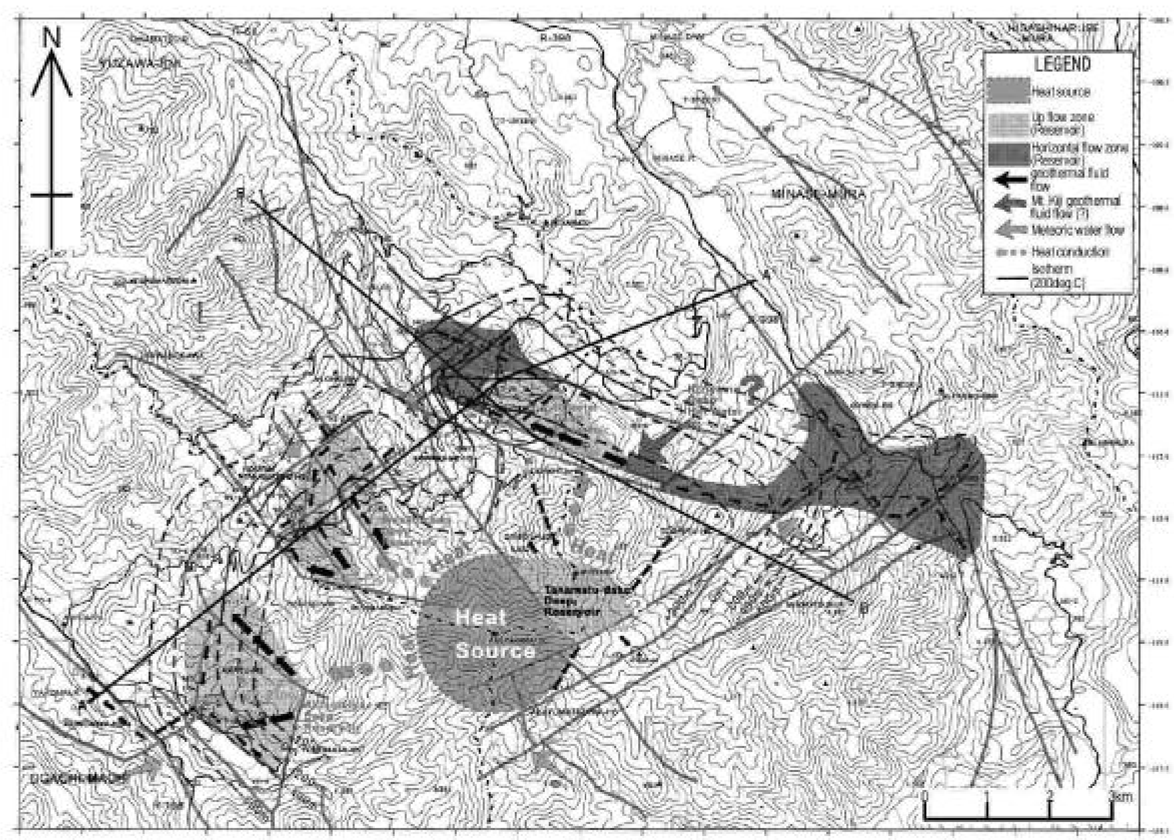

Figure 4. Plan view of a model of geothermal system of the Uenotai geothermal field.

within intrusive rocks occurred in pre-Tertiary basement rocks and their margins.

The center of the heat source is estimated to be about 2 km south of the Uenotai field, beneath Mt. Takamatsudake, at depths below 4,000 m. The subsurface temperature distributions are concordant with the geologic structure and the subsurface temperature was calculated based on the Curie point, at a depth of about 9 km below sea level with an assumed Curie temperature of 570°C.

WNW-ESE and NW-SE trending faults are estimated to be fluid pathways in the subsurface of the study area. The recharge area is estimated to be located around southwestern part of the Uenotai geothermal field where the subsurface temperature is relatively low.

Numerical Simulations

The numerical 3D model covers an area of 64.0 km^2 (8.0 × 8.0 km) around the Uenotai field and the Wasabizawa area with a vertical range of about 1,000 m above sea level and 4,000 m below sea level. Each grid size of the model block varies from 250 to 1,000 m in horizontal and from 200 to 1,000 m in vertical.

Numerical simulation of geothermal fluid dynamics in the Uenotai area is being finalized. Calibration of temperature and pressure by natural-state simulation were made successfully.

OTAKE-HATCHOBARU FIELD

The Otake-Hatchobaru geothermal field is located in central Kyushu. Commercial operations of the Otake and Hatchobaru electric power stations commenced in August 1967 and June 1977, respectively. There are 46 active wells in total in the Otake-Hatchobaru field as of March 2000: 26 production wells and 20 reinjection wells.

In this area basement rocks (pre-Tertiary), Usa group (Miocene), Hohi volcanic rocks (Lower Pleistocene) and Kuju volcanic rocks (Middle-Upper Pleistocene) are distributed in ascending order. These units are composed mainly of andesite and andesitic volcaniclastic rocks though pre-Tertiary basement rocks which consist of crystalline schists and granitic rocks.

Stochastic Analyses

Temperature, pressure and permeability against depth were examined and extrapolated to estimate temperatures at the deeper layers. Temperature and permeability are plotted against depth in a logarithmic scale and a straight line is applied to estimate the relationships. On the other hand pressure is simply extrapolated linearly. The estimated temperature does

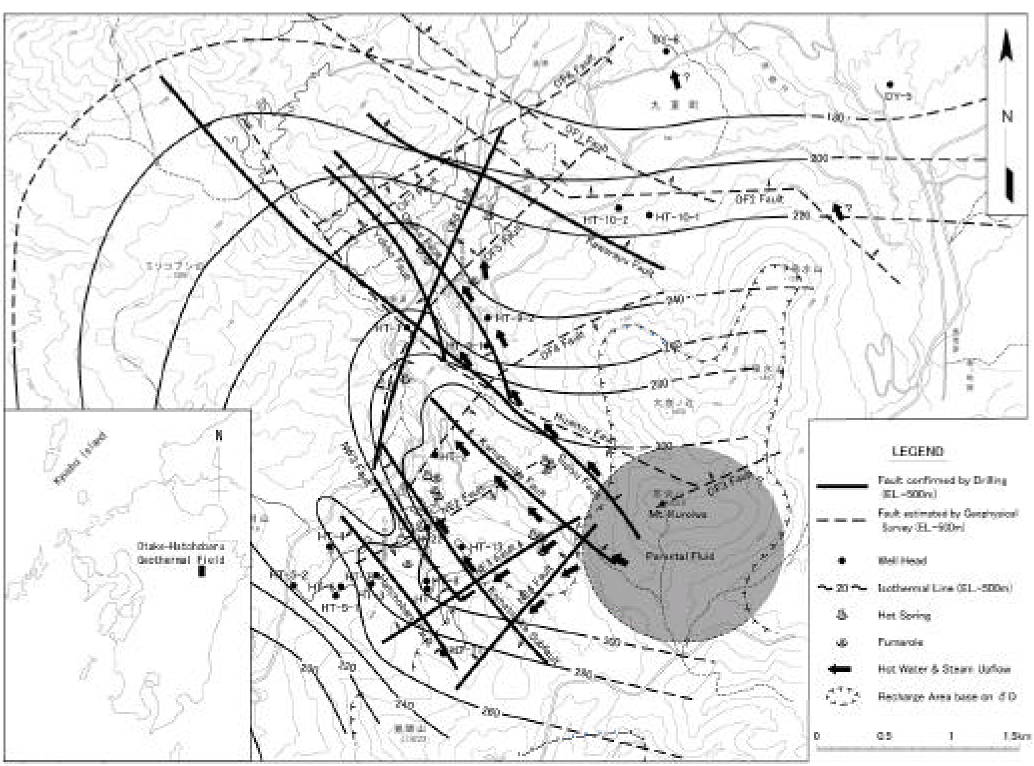

Figure 5. Plan view of a model of geothermal system of the Otake-Hatchobaru geothermal field (Momita et al., 2000).

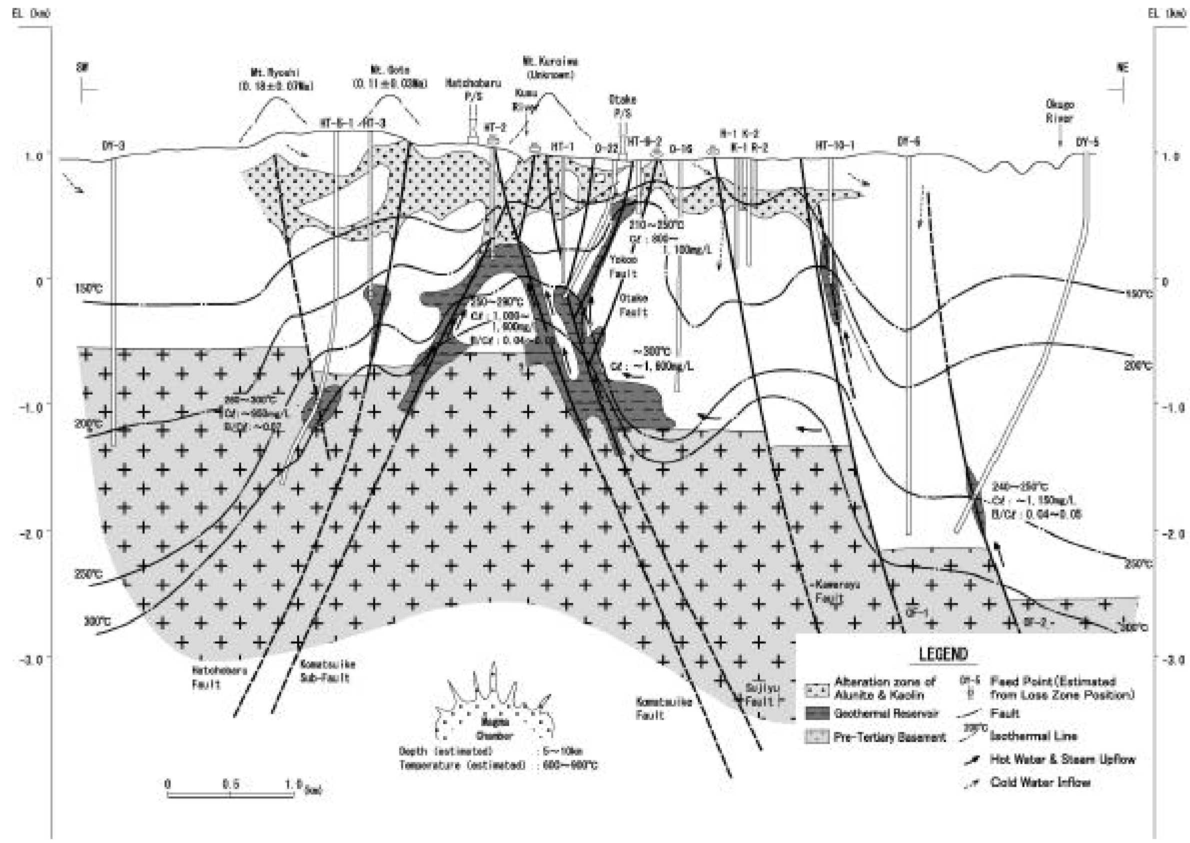

Figure 6. Cross-sectional view of the model of geothermal system of the Otake-Hatchobaru geothermal field (Momita et al., 2000).

Not exceed the saturated temperature.

Conceptual Model

Plan and cross-sectional views of a conceptual model of the Otake-Hatchobaru geothermal field are shown in Figures 5 and 6, respectively. Detailed discussions on the conceptual model of the Otake-Hatchobaru area were made by Momita et al. (2000). The reservoirs are formed in fractured zones, which are developed along the major faults trending a NW-SE direction and the main reservoirs are stratigraphically in the Hohi volcanic rocks. The initial reservoir temperature in the current production zone is estimated to be 250-280°C based on the fluid inclusion analysis results.

The heat source of this area is considered to correspond to a residual magma chamber beneath Mt. Kuroiwa. From theoretical point of view, it is presumed that the heat source of the Otake-Hatchobaru area provides the conductive heat to create the deep temperature conditions. The Curie point in the Otake-Hatchobaru area is estimated to be at a depth of 6 km below sea level where the Curie temperature is assumed to be 570°C.

The interpretation of isotope data of fluids sampled in the region indicates that the geothermal fluids in the Otake-Hatchobaru field are derived almost entirely from meteoric water. The recharge area is located around the southern part of Mt. Kuroiwa. It is considered that the geothermal fluids, which are derived from the parental fluid stored beneath Mt. Kuroiwa, supplies the production at the Otake area.

Numerical Simulations

The numerical model covers an area of 57.7 km^2 (7.8 × 7.4 km) around the Otake-Hatchobaru field. In a vertical direction, the top and bottom of the model block correspond to elevations of about 1,100 m above sea level and 4,000 m below sea level, respectively. Each grid size of the 3D model block ranges from 200 to 800 m horizontally and from 250 to 750 m vertically.

Simulated temperatures and pressures in a natural state were calibrated by borehole measurements at the wells. Examples of the calibration of the measured and simulated temperatures are shown in Figure 7. These results indicate that the numerical model can generally explain how the present temperature distributions of the exploited depths were reached.

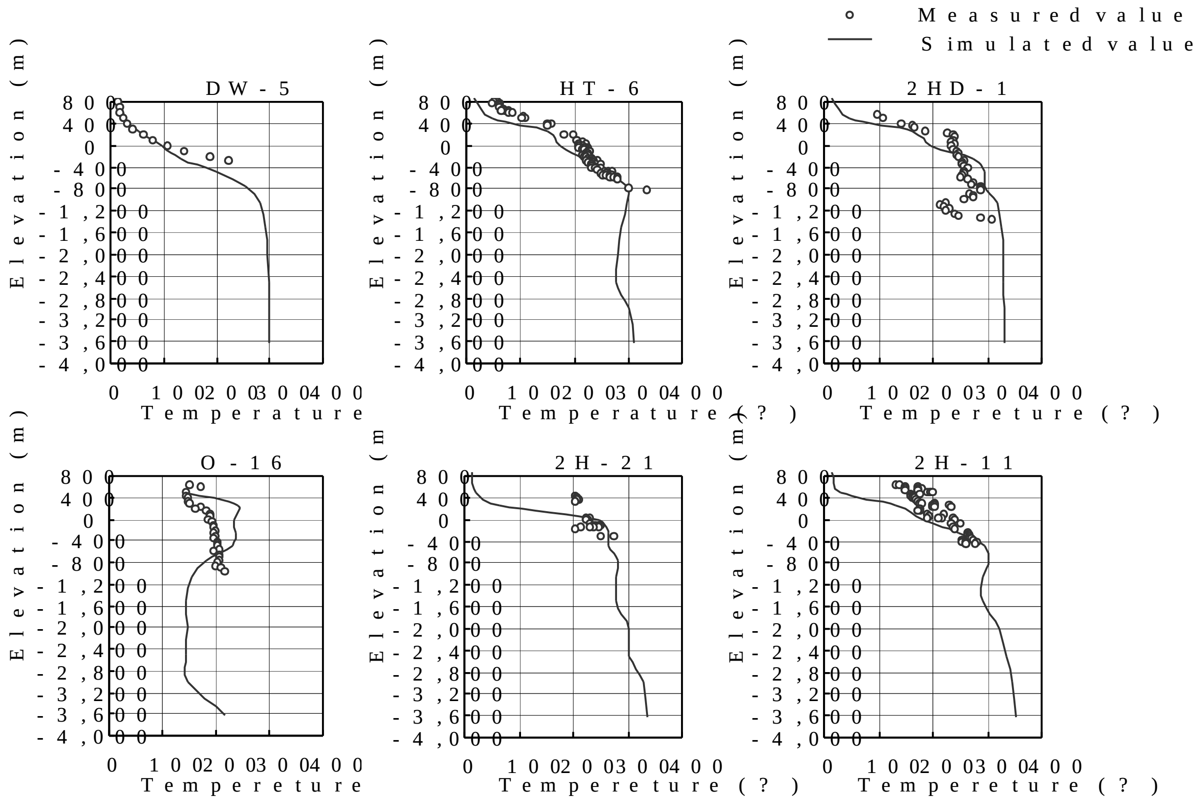

Figure 7. Comparison of measured and simulated temperature profiles of wells in natural state in the Otake-Hatchobaru geothermal field (Momita et al., 2000).

GUIDELINES FOR DEVELOPMENT OF DEEP-SEATED GEOTHERMAL RESOURCES

Guidelines composed of three categories or the development of deep-seated geothermal resources are being examined and as follows;

- Guidelines for exploration methods and techniques
- Guidelines for deep geothermal drilling
- Guidelines for deep geothermal fluid production

In the guidelines development economics also is to be taken into account. The guidelines have already been established for the Kakkonda geothermal field, and these guidelines are being revised in order to apply them to the other areas.

Guidelines for Exploration Methods and Techniques

Exploration methods and techniques for deep-seated geothermal resources are being reviewed. The exploration methods and techniques include newly developed methods such as Multi-frequency Array Induction Logging (MAIL) and Vertical Electro-Magnetic Profiling (VEMP) methods as well as the conventional methods and techniques such as microearthquake analysis and fracture analysis using well logs. Applicability of the exploration methods and techniques taking local variation of geothermal system into account is also being reviewed.

Guidelines for Deep Geothermal Drilling

The existing drilling technologies were employed for drilling a deep exploration well in the Kakkonda geothermal field. The drilling procedures and techniques used in the drilling at Kakkonda were reviewed and arranged for the guidelines for the deep geothermal drilling. Additional information on deep geothermal drilling in other geothermal areas in not only domestic Japan but also overseas countries is being reviewed and incorporated into the guidelines.

Guidelines for Deep Geothermal Fluid Production

The guidelines for deep geothermal fluid production include the prevention of erosion and corrosion of materials such as casing and the surface pipes and the evaluation techniques and procedures of deep-seated geothermal resources.

CONCLUSIONS

(1) The deep-seated geothermal resources in the Uenotai and Otake-Hatchobaru geothermal fields were

successfully evaluated in recent our study.
(2) Two approaches were employed for the estimation of the deep geothermal reservoir parameters: stochastic analyses and numerical simulations.
(3) Several stochastic methods were attempted to obtain better deep subsurface parameters.
(4) Calibrations of measured and simulated values regarding temperature and pressure in natural-state were successfully carried out in both the Uenotai and Otake-Hatchobaru areas.
(5) The methods and techniques used for the evaluation of the deep-seated geothermal resources are to be arranged and included in the guidelines for the development of deep-seated geothermal resources.

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REFERENCES

Momita, M., Tokita, H., Matsuda, K., Takagi, H., Soeda, Y., Tosha, T. and Koide, K. (2000), "Deep Geothermal Structuire and the Hydrothermal System in the Otake-Hatchobaru Geothermal Field, Japan," *Proc. 22nd New Zealand Geothermal Workshop*, 257-262.

Okubo, Y., Akita, F. and Tanaka, A. (1998), "Thermal Gradient Map and Thermal Structural Model—A Case Study of Hokkaido—," Journal of the Geothermal Research Society of Japan, **20**, 1, 15-29. [in Japanese with English abstract.]

Shiga, T., Sato, M., Sato, T., Okabe, T., Osato, K., Takahashi, Y., Inoue, T., White, S. P. and Koide, K. (2000), "Estimation of Deep Reservoir Temperature Distribution Using Stochastic Method in the Uenotai Geothermal Field," *Proc. 22nd New Zealand Geothermal Workshop*, 263-266.

Tamanyu, S., Yoshizawa, M. and Nomura, K. (1995), "Deep Subsurface Temperature Distribution Pattern Estimated from Many Temperature Logging Data: Example of Hohi Geothermal Area, Kyushu, Japan," *Bull. Geological Survey of Japan*, **46**, 313-331. [in Japanese with English abstract.]

Tamanyu, S., Nomura, K. and Yoshizawa, M. (1996), "Deep Subsurface Temperature Distribution Pattern Estimated from Many Temperature Logging Data: Examples of 14 Major Geothermal Fields in Japan," *Bull. Geological Survey of Japan*, **47**, 485-548. [in Japanese with English abstract.]