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PLANNING AND RESULTS OF WELL-DRILLING BASED ON THE INTERPRETATION OF GEOLOGICAL STRUCTURE IN THE HATCHOBARU GEOTHERMAL AREA

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ABSTRACT

For the Hatchobaru geothermal area, the planning of well drilling is done based upon a conceptual model of the geothermal area which is periodically updated using the latest geological information obtained from the latest drillings and from the results of updated reservoir simulations. Actual experiences of recent years show that the drilling plans made using this methodology have been effective.

Production well H-31 was designed to tap the NE4 fault at a depth of 2,750 m and the Komatsuike sub-fault at a depth of 7,800 m. According to the results of drilling, the presence of feed points was confirmed at 2,177 m and 1,790 m. The production test of this well rendered an output equivalent to 6,140 kW. These results confirm the adequateness of the geothermal conceptual model constructed for the Hatchobaru geothermal area.

1.0 INTRODUCTION

The Hatchobaru geothermal area is located at the northwestern side of Mt. Kujyu, in central Kyushu. The Kyushu Electric Power Company (KEPCO) began the development and investigation of this area in 1967. The Hatchobaru Power Plant No.1 unit (55MW) started commercial operations in 1977, the No.2 unit (55MW) started in 1990, and both units have been operating continuously since that time.

The geothermal conceptual model for the Hatchobaru geothermal system was constructed, synthesizing many data obtained through the application of various methodologies and surveys and through the incorporation of results of well drilling (Fujino, 1985; Shimada and Fujino, 1995 and Yoshiyama et al., 1996). To maintain the rated power output of the power plant, a program to drill future wells was made through the application of reservoir simulation techniques (Tokita et al., 2000). According to this program, the drilling of about 1 production well is required per year. The drilling program is revised every year and before a well-drilling several alternatives for its direction and depth are analyzed within the established drilling policy indicated by the program. The latest data of well testing and well geological data are incorporated into the model to update the model and drilling plans.

This paper discusses the concepts involved in the well drilling plan and illustrates the method presenting the results of drilling well H-31.

2.1 GEOLOGICAL STRUCTURE

The Hatchobaru geothermal area is located at the Kujyu Volcanic zone in the Central Kyushu. The geological sequence in this area is represented by the Quaternary, the Kujyu and the Hohi volcanic rocks which are overlying the Tertiary volcanic rocks and the Pre Tertiary basement rocks.

The geothermal reservoir is found along NW-SE and NE-SW trending faults (Fujino, 1985 and Shimada and Fujino, 1995). The Hatchobaru fault, the Komatsuike sub-fault and the Komatsuike faults trend in NW-SE direction. The NE2, the NE3 and the NE4 faults trend in NE-SW direction (Fig. 1).

According to the production logging of recent years, the geothermal reservoir is hosted in fracture zone developed along faults.

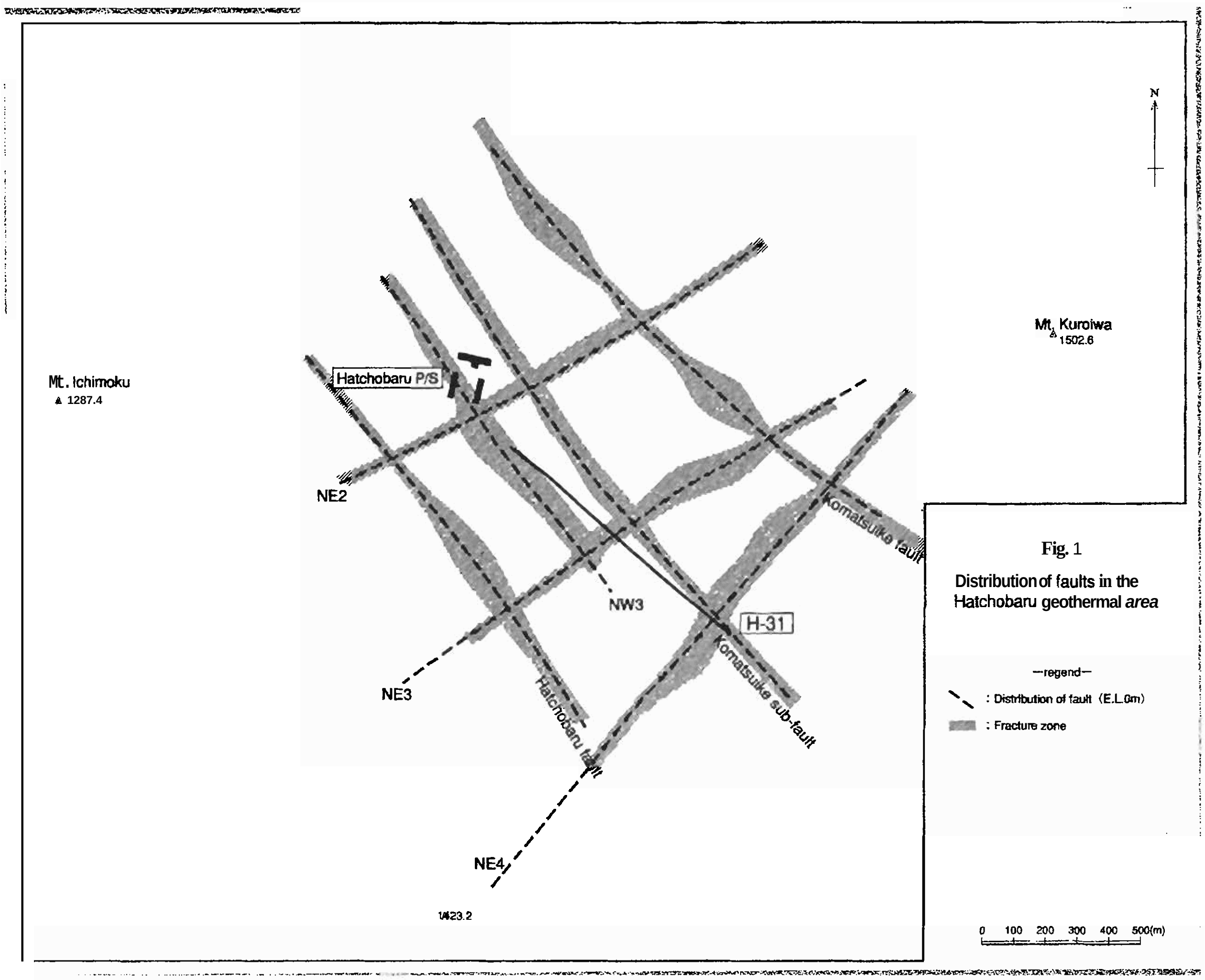

Figure 1. Distribution of faults in the Hatchobaru geothermal area.

2.2 PLANNIG FOR PRODUCTION WELL DRILLING

One production well per year has been drilled in the Hatchobaru geothermal area to maintain the generating electricity output of 110MW. Their targets have been established upon results of reservoir simulation. Through reservoir simulation the productivity of each fault have been estimated. Therefore those faults with enough production capacity and that can be reached through economic drilling and not representing interference to other wells are selected as production drilling targets.

Accordingly, in the following paragraphs a discussion is presented regarding the targeting and interference between the wells, to determine detailed drilling specifications.

Targeting

The target will be a fault and its associated fracture zone in which geothermal fluids are flowing. Fault distribution is estimated through the analysis of gravity lineament and electric discontinuities. The extent of the geothermal reservoir around the fault is estimated from the distribution of the feed points confirmed by production logging and the quality for commercial production of the reservoir fluids is evaluated though the analysis of geochemical information of existing wells.

Interference to adjacent wells

At present, about 20 production wells are producing in the Hatchobaru geothermal area. Interference between some wells has been detected recently. The distance between feed points of existing and planned wells is determined to avoid interference. According to the actual experience, problematic interference between wells is avoided if the distance between feed points is more than 200m. Therefore, wells are planned so as to leave a separation of more than 200 m between feed points.

Sometimes, it is necessary to plan wells near existing wells. In this case, periods to monitor production condition are proposed to prevent effects on the power plant.

If contamination with drilling mud is foreseen in some well, this well is temporarily taken out from the generation system or it is decided to stop its production in the worst case. As for those wells, which might affect the operation of other wells, the final casing depth is set so as to leave a distance to the feed point of adjacent wells of more than 200 m.

Well direction, depth and casing program are specified on the basis of above discussion. The direction and depth of drilling are determined with the purpose of productivity while the casing program is determined so as to keep minimum interference between wells.

2.3 ACTUAL EXAMPLE

Well drilling plan

The NE4 fault was selected as the target for well H-31. According to simulations resutts, an output of about 5000kW was estimated.

However there was a risk in the permeability of the NE4 fault, because a number of wells drilled nearby the planned target for well H-31 resulted poor. As an alternative, the Komatsuike fault was also selected as a target for this well.

Figure 2 shows the geothermal conceptual model of the Hatchobaru geothermal area and the target selected for this well. A drilling depth of 2300 m was designed to cross all the selected targets. The relative position of the drilling pad and the target required intercepting fault NE3. However, as many production wells are in actual production from the NE3 fault, interference problems were foreseen, and thus this fault was excluded from the target list of well H-31. To prevent interference it was decided to let the casing cover the portion intercepting the NE3 fault.

The database and conceptual model indicated that depth to encounter alteration, circulation loss and changes in water level and foreseeable problems were as follows:

NE3 fault

Because there are more than 20 production wells, interference was expected.

(a) Depth of interception
Depth to encounter the NE3 fault was around 1,300 m. Therefore casing length was decided to cover this depth.

(b) Atteration
Kaolinite was expected at depths close to the NE3 fault because of the presence of this mineral was confirmed by the drilling of well 2H-21.

(c) Monitoring for Interference
Since production wells tapping fault NE3 are in production, monitoring of these wells was programmed to be carried out during the drilling of the well H-31.

Komatsuike sub-fault

(a) Depth of interception
Well H-31 was expected to intercept the Komatsuike sub-fault at a depth around 1,800 m.

(b) Alteration
A pyrophyllite was expected around the depths well H-31 would intercept the Komatsuike sub-fault because this mineral have been confirmed during drilling of wells H-26 and H-30.

(c) Circulation loss
A large circulation loss was predicted around the Komatsuike sub-fault because of the multiple circulation losses occurred around this sub-fault when drilling wells H-26 and H-30.

(d) Water level in the well
The water level in this well was expected to be below the 800 m.

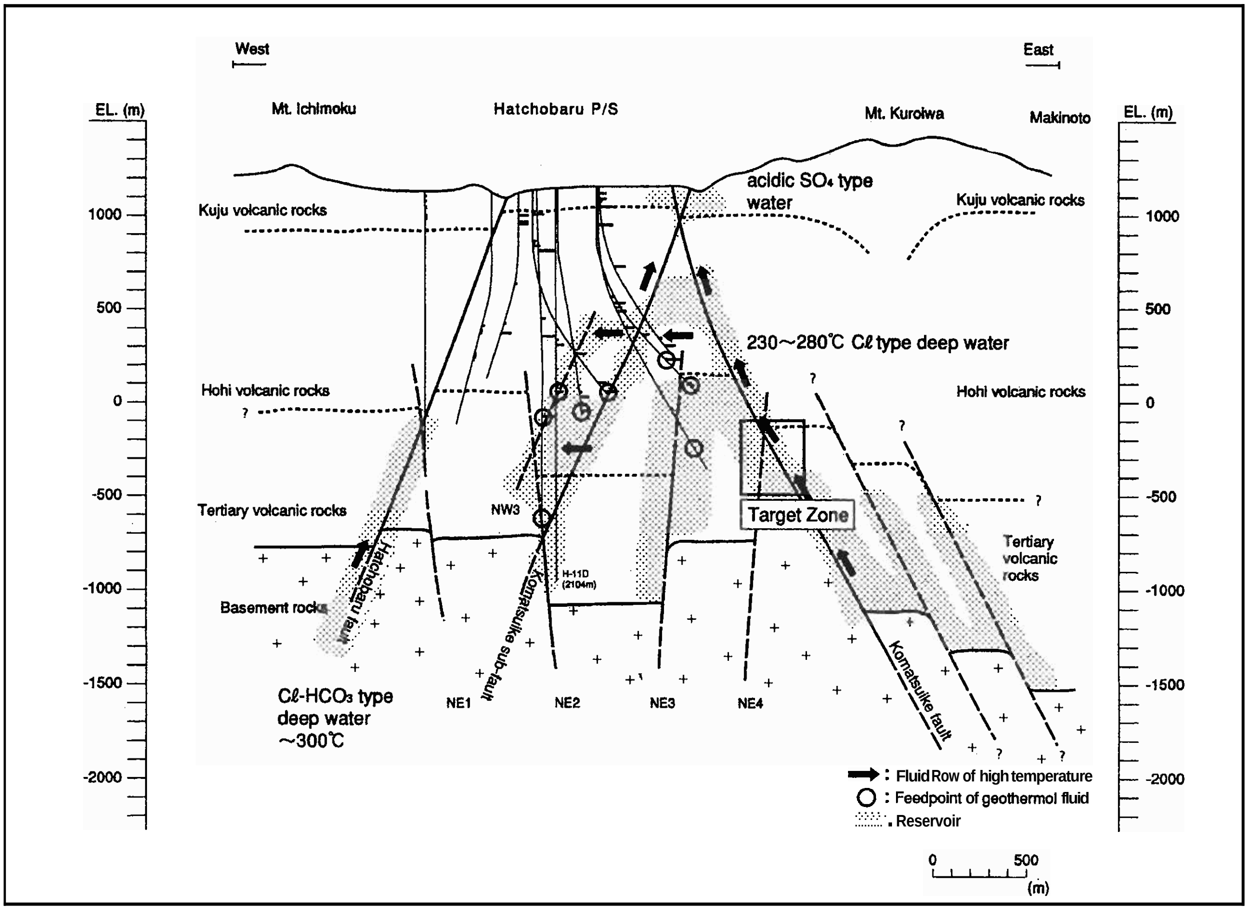

Figure 2. Geological section of Hatchobaru geothermal area (modified after Shimada et al., 1995).

NE4 fault

(a) Depth of interception
The depth to encounter the NE4 fault was expected to be 2,150 m.

(b) Alteration
The alteration around the NE4 fault was weak at the feed points of well 2H-19 but large amount of anhydrite was confirmed. For this reason, anhydrite was expected as the well would be approaching this fault.

(c) Circulation loss
A large amount of circulation loss was expected around the NE4 fautt from the result of the 2H-19 drilling.

(d) Water level in the well
The water level when well 2H-19 intercepted the NE4 fault was 890m. However, well H-31 was planned to intercept not only the NE4 fault but also the Komatsuike sub-fault, therefore it was difficult to estimate the water level in the well.

Drilling results

The result of the H-31 drilling showed that it intercepted fault NE3, Komatsuike sub-fault and NE4 fault at the depth indicated below. Figure 3 shows alteration encountered in the well H-31.

NE3 fault

A pyrophyllite was confirmed around the depth of 1,500 m deeper than expected. A large amount of circulation loss occurred at a depth of 1,470 m. As it was expected, the circulation loss was large close to the NE3 fault. Thus, it was concluded that the well H-31 had reached the NE3 fault around this depth of large water loss. Interference to other wells was not detected

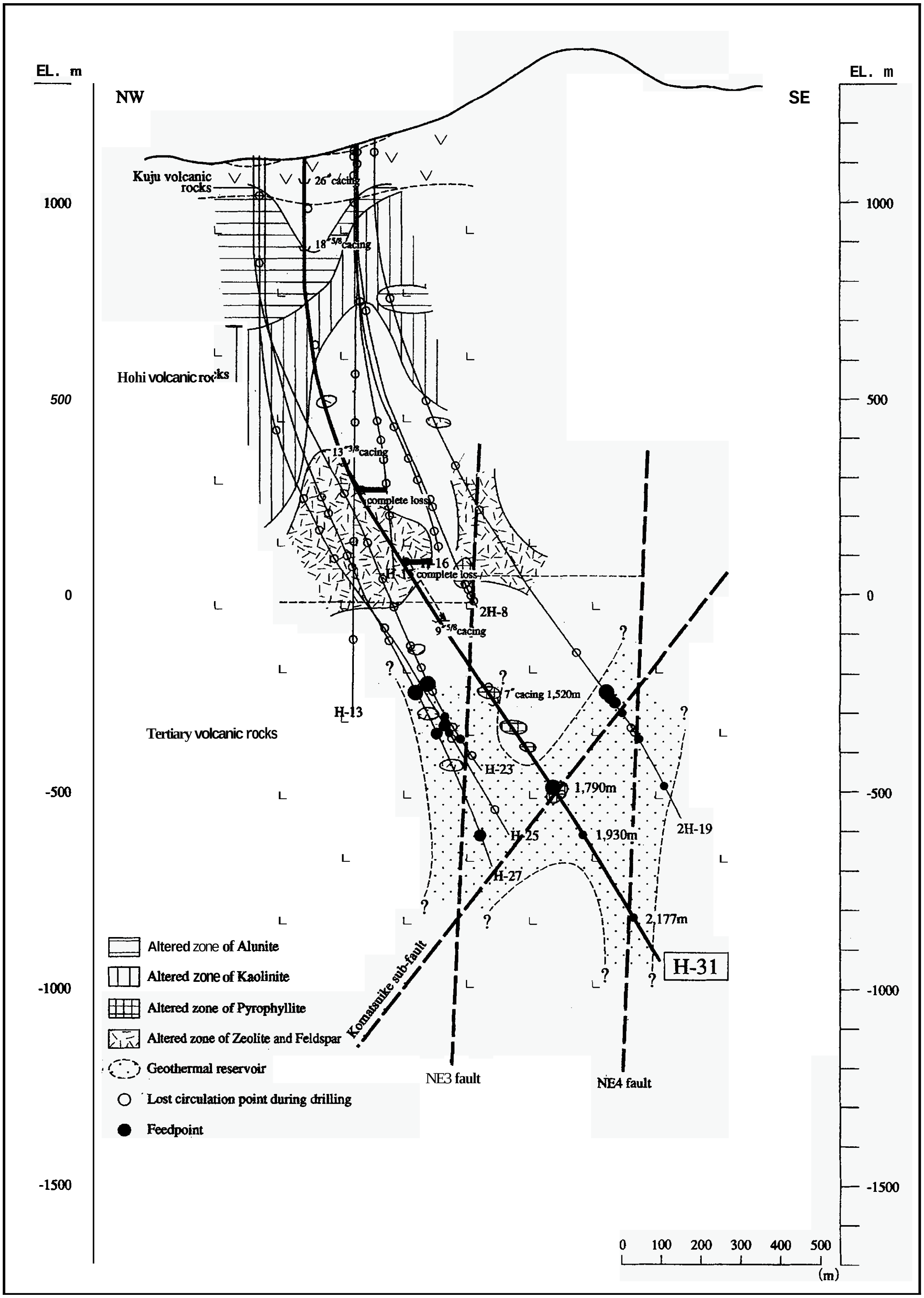

Figure 3. Geological section in the H-31 drilling direction.

when well H-31 approached and intercepted the NE3 fault. The well was plugged to the depth of 1,520 m with a liner cementing in order to prevent possible interference to other production wells. Well H-31 is in production ever since and no interference to other wells producing from NE3 fault has been detected.

Komatsuike sub-fault

A shallower feed point was confirmed at a depth of 1,790 m according to the results the production logging and another feed point was confirmed at a depth of 1,930 m. A pyrophyllite was confirmed around the depth of 1,788 m. It was interpreted that the shallower feed point encountered at the depth of 1,790 m along the Komatsuike sub-fault was that expected when planning the drilling. A characteristic alteration could not be confirmed around the feed point at 1,930 m depth. Since the azimuth of well H-31 is close to that of the Komatsuike sub-fault, it was interpreted that this well penetrated a large portion of the fracture zone associated to the Komatsuike sub-fault and that the feed point at the depth 1,930 m corresponds to this fracture zone. The water level after intercepting this fracture zone was detected at 940 m depth which is deeper than expected from the reservoir pressure along the Komatsuike sub-fault.

NE4 fault

A remarkable temperature anomaly was confirmed at the depth of 2,177 m according to the result of the production logging. Increasing amounts of anhydrites at the depth around 2,200 m shows the existence of fractures and thus it was interpreted as a feed point. These conditions are similar to those of well 2H-19. The feed point encountered at the depth of 2,177 m is interpreted as corresponding to the reservoir along the NE4 fault. The water level when the well intercepted this fault was recorded at the depth of 792 m. Since well H-31 tapped not only the reservoir along the NE4 fault but also that around the Komatsuike sub-fault it is interpreted that the water level is controlled by the pressure of both reservoirs.

3.0 DISCUSSION

Reservoirs tapped by well H-31

Feed points were confirmed around the Komatsuike sub-fault and the NE4 fault according to the results of the production logging. Thus, it is clear that the reservoir hosted around the Komatsuike sub-fault has better production capacity in well H-31,

Subsurface conditions confirmed by the drilling

Feed points were confirmed at the depth of 1,790 m, 1,930 m, and 2,177 m. It is interpreted that feed points at the depths of 1,790 m and 1,930 m tapped the reservoir along the Komatsuike sub-fault while the feed point encountered at the depth of 2,177 m tapped the reservoir hosted along the NE4 fault. Feed points at the depth of 1,790 m and the 2,177 m were close to the depth expected when planning the well drilling. The extent of the reservoir along the Komatsuike sub-fault was larger than expected. Well H-31 intercepted fault NE3 deeper than expected when planning the well drilling.

The alteration around the Komatsuike sub-fault and the NE4 fault is similar to that estimated. The alteration around the NE3 fault was slightly different from that estimated.

The effect of the countermeasure

Interference among wells during drilling was not detected as per the result of monitoring existing wells around NE3 fault. In addition, no interference among wells producing from fault NE3 has been detected during the production of well H-31. Plugging the well at the depth of 1,520 m using liner cementing was an effective measure. Yoshiyama et al. (1996) reported on the damage of interference among producing wells during drilling. As the number of wells increases, risk of damaging is larger. Therefore it is important to update the geothermal conceptual model after the information about drilled well was obtained.

Productivity of well H-31

An output of about 5,000 kW was estimated for well H-31 at planning. As the well was tested and kept in continuous production, its output has been recorded at 6,140 kW.

4.0 CONCLUSION

- The subsurface conditions expected when planning the drilling of well H-31 were close to those encountered during the actual drilling operation. It was shown that planning the drilling of wells based upon an updated geothermal conceptual model is effective to keep the rated power output of the power plant.

- The measure, such as liner cementing, taken to prevent interference among producing wells is effective.

- Since well H-31 maintains a high power output, it is considered that the planning and well drilling was successful.

- It is important to plan the drilling of wells based upon a long-term prediction of reservoir response to exploitation Losing the reservoir simulation.

ACKNOWLEDGMENTS

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