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DEVELOPMENT OF THE DRILLING SUPPORT SYSTEM AS A PART OF THE MWD SYSTEM FOR GEOTHERMAL WELLS

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ABSTRACT

Many geothermal wells are drilled in formations of hard volcanic rock, with open fractures, at high temperatures and pressures. Operating companies and government agencies spend a lot of money dealing with frequent lost circulation and other problems. Since many geothermal targets are located in high angle fractures, and most wells are drilled on sites of limited size in mountainous areas in national parks, directional drilling technology is very important in order to hit the target from a restricted location. "Measurement While Drilling (MWD)" technology, where the drilling direction and the tool face direction are known "in real time" during drilling, is the most effective method for serious directional, controlled drilling. However, MWD technology is based on oil and gas technology and the newest MWD systems on the market have maximum operating temperatures of almost 180 Deg.C. Therefore, we can not use these MWD systems to control the drilling direction in the higher temperature zones of the target. GERD and Mitsui Zosen Group (Akishima Laboratory Co. and Mitsui Zosen Co.) are developing a high temperature MWD system that can be operated under a condition of 200 Deg.C in the "Development of High Temperature Measurement While Drilling System for Geothermal Wells" Project (a part of "New Sunshine Project" of MITI). This project has been conducted by NEDO since 1991.We are developing a "Drilling Support System" that consists of the "Directional Control Support System" and the "Formation Evaluation Support System " through this project.

The Directional Control Support System consists of a "Well Trajectory Planning System", a "Well Trajectory Visualization System", and a "Well Trajectory Prediction System". The system can present the measured data and the well trajectory with a 2-dimensional plane view/Cylinder view/3-dimensional bird's-eye "in real time". In addition, the system can be used to plan and predict well trajectory and use a new BHA that the driller can select on site.

The Formation Evaluation Support System consists of a "Formation Temperature Analysis System" and a "Formation Pressure Analysis System". The "Formation Pressure Analysis System" is still in its basic design, but the "Formation Temperature Analysis System" is almost completed. The "Formation Temperature Analysis System" is the prediction system for equilibrium formation temperature while drilling, based on the borehole temperature simulation code "MWDTEMP2" that is modified from "GEOTEMP2" (Mondy & Duda, 1984); using a non-linear least square inversion technique.

This paper shows the function comparison of the "Drilling Support System", analysis of results using actual data, and consideration for the effect of drilling efficiency by applying the system to directional drilling. Figure 1 shows concept of MWD system, and figure 2 shows concept of the "Drilling Support System".

1. INTRODUCTION

In general, the analysis system for commercial MWD tools consists of proprietary software, with a mud pulse detection system, which is used by service companies in the oil field. Additionally, the system is large. Therefore, we are developing a MWD analysis system of small size, which uses real-time data collection from MWD. It consists of the following elements:

- Directional Control Support System: This system can plan the well trajectory for geothermal well drilling; indicate the well trajectory based on data detected by MWD; and predict the well trajectory while drilling.
- Formation Evaluation Support System: This system can estimate the formation temperature and borehole pressure while drilling, and determine formation characteristics to facilitate decision making to either stop drilling or to continue. It can also estimate the bottom hole circulating temperature for the operating environment of a MWD tool.

2. DIRECTIONAL CONTROL SUPPORT SYSTEM

2.1 Well Trajectory Visualization System

Figure 3 shows 2-dimentional plan and section views of the well path. The plan view and section view show the current well trajectory by combining MWD data with drilling depth data acquired from mud logging or other sources. The origin of well path coordinates is the wellhead. The current well path, along with other circumference well path, planned well path on a plan view, a section view, and a 3-dimentional view can also be shown (figure 4). The direction of section is optional on the section view, and the viewpoint can be changed on the 3-dimentional view. Another advantage is the ability to change from a plan view to a cylinder view to detect encounters with other wells. We can select the view mode depending on the drilling case. Also, it can indicate the fracture plane, lost circulation depth, and target (sphere, cube). Figures 5 and 6 show a Log view and a Meter view. The Log view can show the drilling parameters (WOB, TOB, TF, Azimuth, Inclination, Temperature, Pressure, Inside Tool Temperature, etc) from MWD, mud logging and so on, by time scale. The Meter view, can also show the drilling parameters by an analog indicator.

2.2 Well Trajectory Planning System

Figure 7 shows the Well Trajectory Planning System. The Well Trajectory Planning System can be used in the 5 following ways:

- Build/Turn Rate & Target Depth: Plan for a simple 2-dimentional well trajectory (vertical section, build section) and 3-dimentional well trajectory (only turn angle);
- Dogleg/TF & Target Depth: Plan for 2D and 3D well trajectory of down-hole motor section;
- Dogleg/Turn-Hold: Plan drilling to a target by down-hole motor BHA, afterwards using an angle hold rotary BHA;
- Target Point (Dogleg/TF): Plan for drilling by down-hole motor to target;
- Dogleg & Constant TF: Plan for 2D and 3D well trajectory section of constant TF with down-hole motor.

We can confirm the planed well trajectory on 2D and 3D views immediately.

2.3 Well Trajectory Prediction System

The Well Trajectory Prediction System can correspond to rotary BHA drilling and mud motor BHA drilling. Bit direction or well trajectory is controlled mainly by the direction of force on the bit. The aim of the Well Trajectory Prediction System is to calculate the direction of force on bit for dynamic BHA analysis; establish the MWD parameters; determine the BHA; and predict the well path. The well trajectory prediction program was improved for mud motor BHA (Nakashima et al, 1994) and rotary BHA (Nakashima et al, 1995). It is difficult to determine information on formation anisotropy. Therefore, we have improved the system to include a formation evaluation function (Ujo et al, 1996). This program is based on equations (Jogi et al., 1988) of equilibrium for BHA to calculate the force acting on the bit and Ho's (Ho, 1987) definition of bit anisotropy, to determine the direction of drilling. Figure 8 shows the results used to predict the well path. It was a better match to the actual well path considering the effect of the formation anisotropy.

3. FORMATION EVALUATION SUPPORT SYSTEM

3.1 Formation Evaluation Support System

Estimation of the formation temperature is an important process when deciding whether drilling should be stopped or continued. We have modified the well bore thermal simulator "GEOTEMP2", which was originally developed by Mondy and Duda (1984), in order to take into account lost circulation and a convection model within the formation. We have also developed a numerical inversion code (named "MWDTEMP2") to estimate formation temperatures from the outlet mud and bottom-hole temperatures while drilling (Takai *et al*., 1994, Takahashi *et al*., 1996, 1997). This paper reports on an attempt to estimate formation temperature from the inlet and outlet mud temperatures while drilling.

Figure 9 shows the input data for this model. In this investigation, the drilling history was simplified and inlet and outlet mud temperatures during drilling were pre-calculated using the "GEOTEMP3" model; which is a forward model for convection and lost circulation as modified by White (1997). These temperatures were used as input to estimate formation temperatures. Figure 10 shows the resultant formation temperatures estimated by inversion of inlet and outlet mud temperatures. Error of the estimated temperature tends to be large at depths greater than 1,000 m. Figure 11 shows the result when using bottom-hole temperature. In this case, using the bottom-hole temperature improved the accuracy. Therefore, in cases where depth is increased or a temperature anomaly exists, the accuracy of the estimation of formation temperature is expected to improve by taking bottom-hole temperature into account when drilling using MWD data.

4. DISCUSSION

In recent years, scientific well drilling techniques have progress rapidly. However, there is a need for immediate analysis of "real-time" bottom hole information and application of the results while drilling. We expect the effects on directional drilling from Drilling Support System to be as follows:

- Acquire and control the well trajectory more accurately by applying the Directional Control Support System in the field;
- Evaluate the borehole formation while drilling and to allow a judgement to stop drilling to be made by applying the Formation Evaluation Support System.

The system will be good application to facilitate progress in improve drilling efficiency.

5. FUTURE PLAN

These systems can be operated on the Unix OS. However, the personal computer is getting more powerful. Therefore, we have modified the codes (Well Trajectory Prediction System, and Formation Evaluation Support System) to run on the Windows OS. We will be modifying all systems into PC versions to allow easier use in the future.

ACKNOWLEDGEMENTS

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REFERENCES

Ho, H.S. (1987). *Prediction of drilling trajectory in directional well via a new rock/bit interaction model.* SPE 16658.

Jogi, P.N., Burgess, T.M., and Bowling, J.P. (1988). *Predicting the build/drop tendency of rotary drilling assemblies.* SPE Drilling Engineering.

Yew, C.H. and Zhang, X.C. (1994). *Study of BHA bending oscillations.* Report, The University of Texas at Austin.

Nakashima, S., Nakata, H. and Takasugi, S. (1995) *Development of the Well Trajectory Prediction System As a Part of the MWD System for Geothermal Wells.* Geothermal Resources Council Transactions, Vol.19, 331-338pp

Ujo, S., Shigemasu, M., Nakashima, S., Osato, K. and Nakata, H. (1997). *Development of Well Trajectory Prediction System as a Part of MWD System for Geothermal Well.(Part3).* 1997 Annual Meeting, the Japanese Association for Petroleum Technology Abstracts. 046

Mondy, L. A. and Duda, L. E. (1984). *Advanced Wellbore Thermal Simulator GEOTEMP2 USER Manual.* Sandia Report, SAND-84-0857, 147pp.

Takahashi, W., Osato, K. and Takasugi, S. (1996). *The Estimation of the Formation Temperature from the Input and Output Mud Temperature While Drilling. - Investigation by the Actual Borehole Data (1) -.* 1996 Annual Meeting Geothermal Research Society of Japan Abstracts with Programs, B17.

Takahashi, W., Osato, K., Takasugi, S. and White, S. (1997). *Estimation of the Formation Temperature from the Inlet and Outlet Mud Temperatures While Drilling.* Proc. 22nd Workshop on Geothermal Reservoir Engineering, Stanford University, SGP-TR-155

Takai, K., Hyodo, M. and Takasugi, S. (1994). *Estimating of Equilibrium Formation Temperature by Curve Fitting Method and It's Problems.* Proc. 19th Workshop on Geothermal Reservoir Engineering, Stanford University, pp65-73.

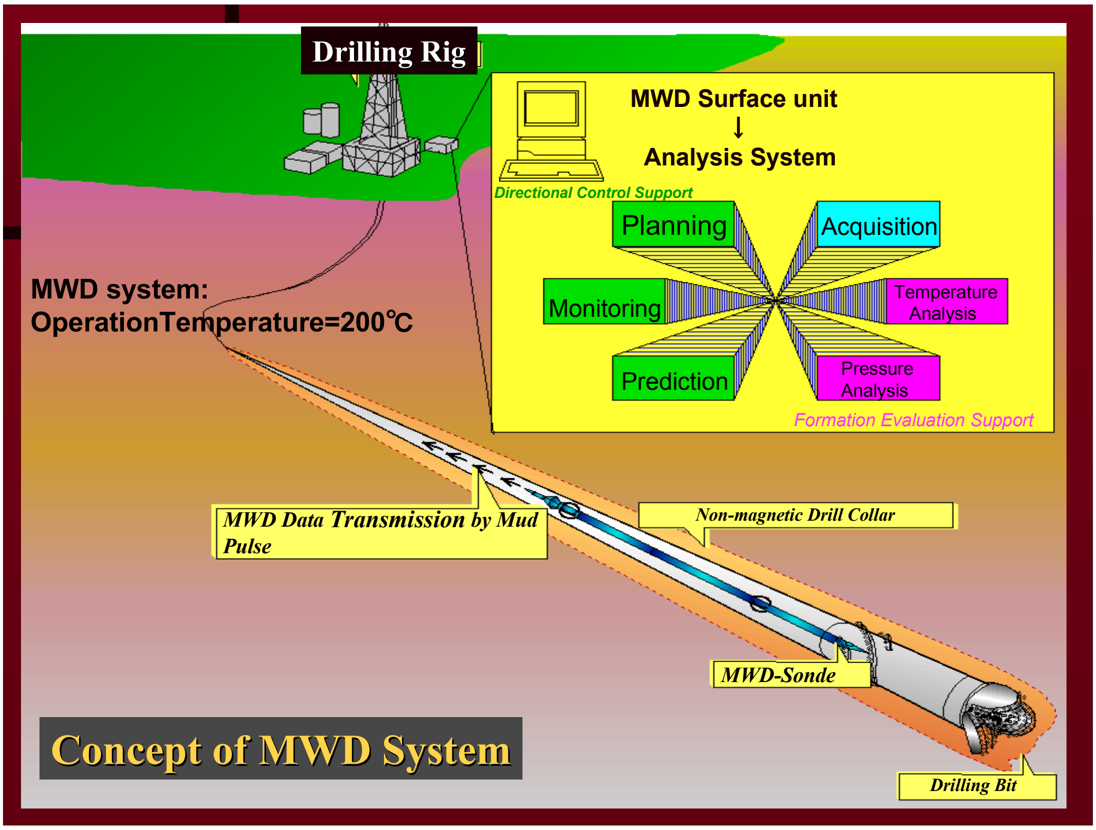


Figure 1. Concept of MWD system

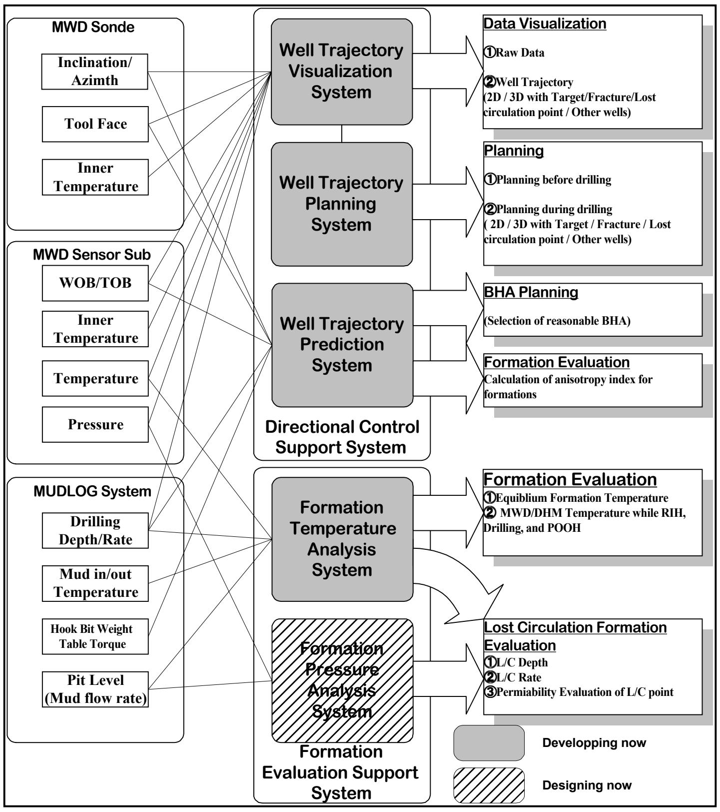


Figure 2. Concept of Drilling Support System

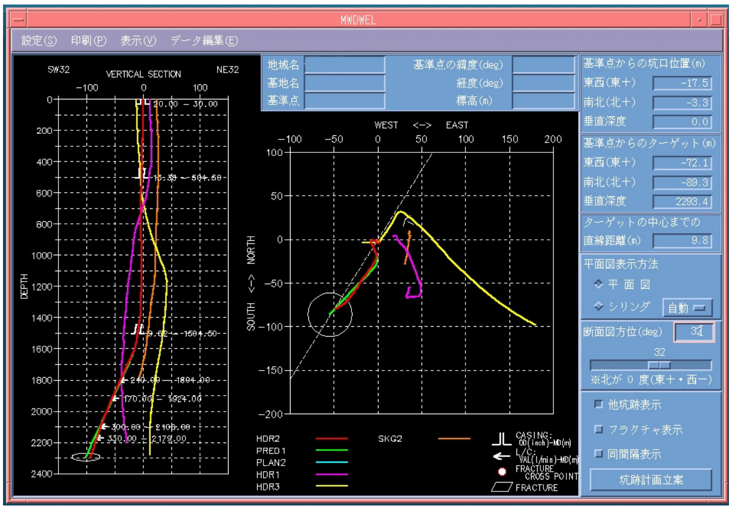


Figure 3. 2-dimentional plan view and section view

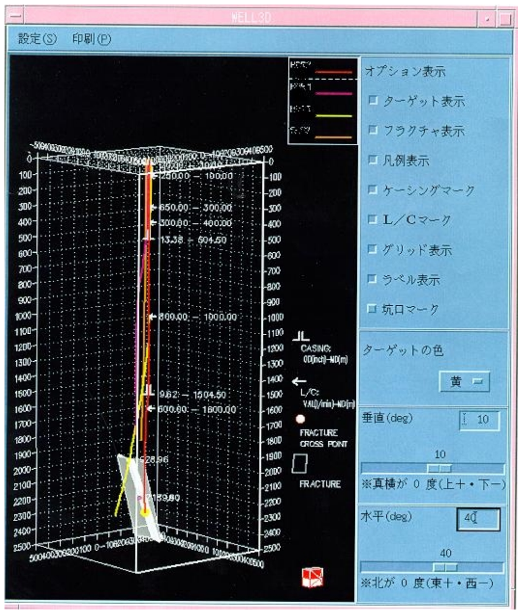


Figure 4. 3-dimentional view

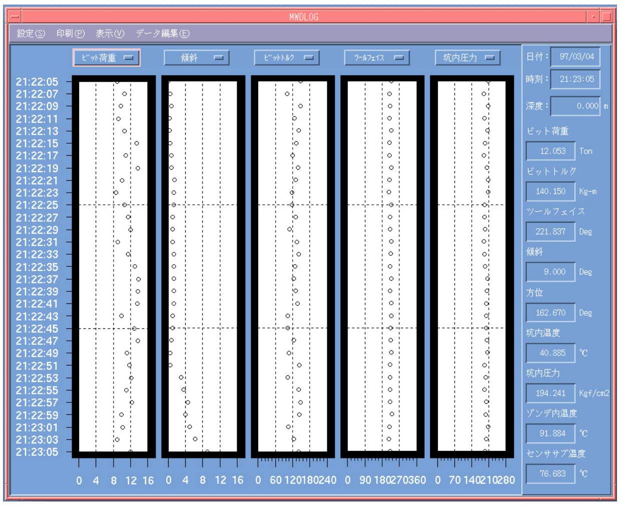


Figure 5. Log view

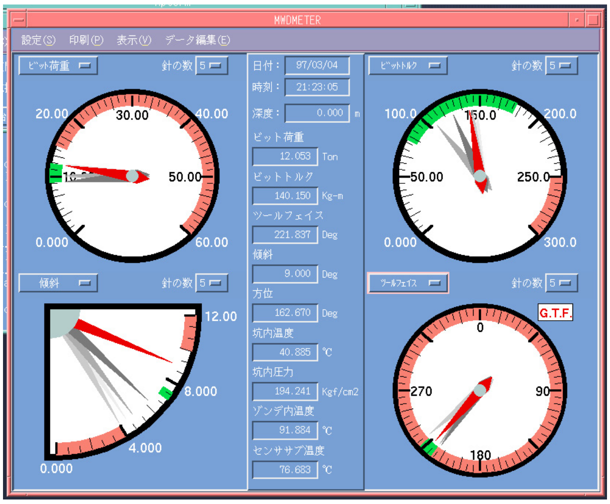


Figure 6. Meter view

Figure 7. Well Trajectory Planning System

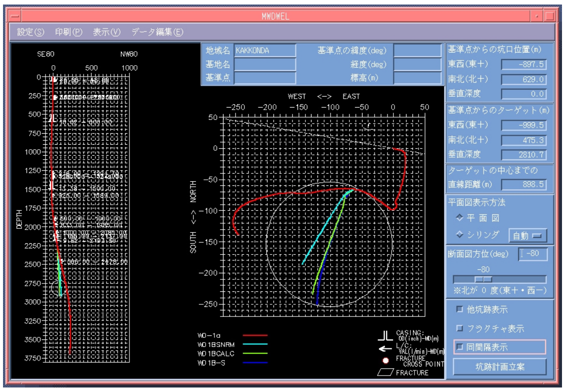


Figure 8. Example for Well Trajectory Prediction

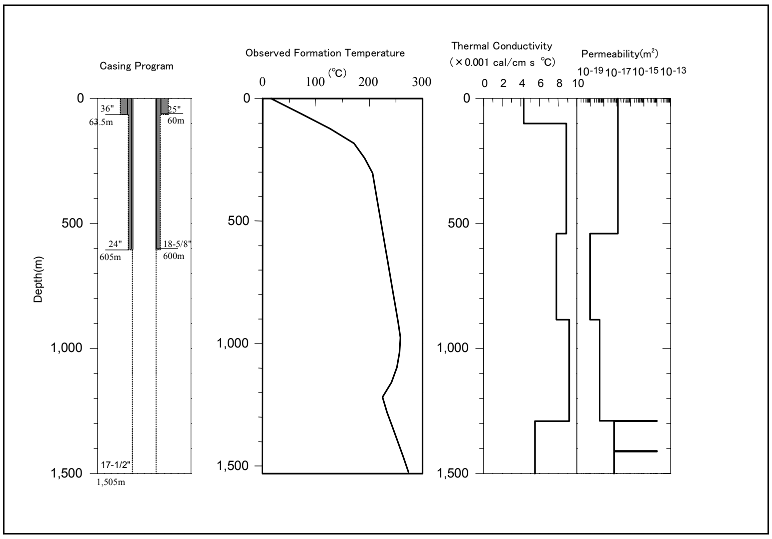
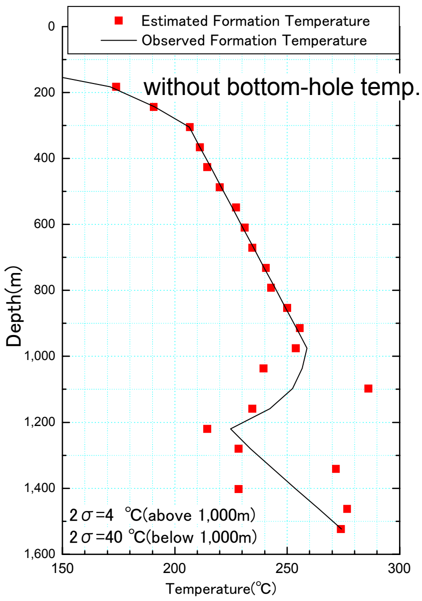


Figure 9. Well Data for inversion (Casing program,Observed Formation Temp.,Thermal conductivity, Permeability)



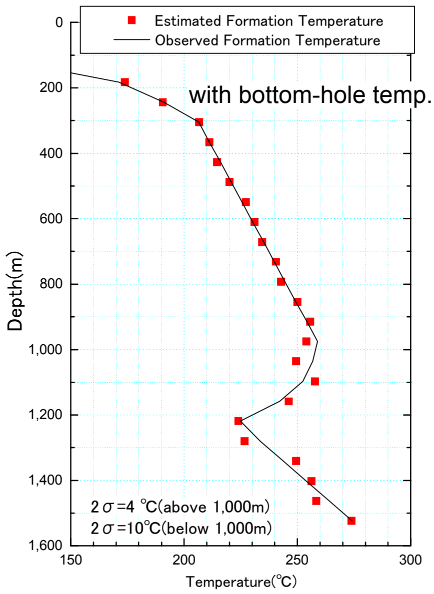


Figure 10. Estimated formation temperature by inversion Figure 11. Estimated formation temperature by inversion with BHT