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HIGH TEMPERATURE LOGGING FOR BASIC DEVELOPMENT OF HDR RESERVOIRS

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ABSTRACT

The second phase of the Hot Dry Rock (HDR) Geothermal Development Program at Fenton Hill, New Mexico, consists of two boreholes, directionally-drilled in a northeast direction, inclined at an angle of 35°, with a vertical separation of 365 m (1200 ft). The two boreholes will be connected by 12 to 15 vertical parallel fractures to make a geothermal reservoir calculated to produce 20 MW(e) for 20 years. Accurate temperature measurements, borehole caliper logs, and directional surveys are required for the successful development and operation of this man-made system. Obtaining these data is extremely difficult because of the bottom hole static temperature of 335°C (635°F) at a depth of 4660 m (15,289 ft), the 35° deviation, the abrasive formation, and the presence of sticky drilling residue products.

The efforts of Dresser-Atlas, Sperry-Sun, and the Geoscience Instrumentation Group of the Los Alamos National Laboratory during July, August, and September 1980, to obtain these data are presented as a case history. The temperature logs and borehole directional survey produced realistic results; but the borehole caliper measurements were inconsistent and unreliable, due to the developmental stage of the caliper tools.

INTRODUCTION

Drilling of EE-2 at the Fenton Hill Site in northern New Mexico was begun in April 1979 and concluded in May 1980, at a depth of 4660 m (15,289 ft). The hole was drilled with 31.1-cm (12-1/4-in.) tungsten carbide button bits to a depth of 3530 m (11,580 ft) and then completed with 22.2-cm (8-3/4-in.) bits. Kickoff point for the deviated section of the hole was 1981 m (6500 ft), and 24.4-cm (9-5/8-in.) casing was set to a depth of 3529 m (11,578 ft). The open-hole well bore below the casing shoe will constitute the heat transfer zone (Brittenham, 1980) (Figure 1).

Direction of EE-2 during drilling was controlled by Scientific Drilling Control's "EYE" steering tool, and was corroborated by Eastman-Whipstock Type E single-shot surveys taken every 20 m (60 ft).

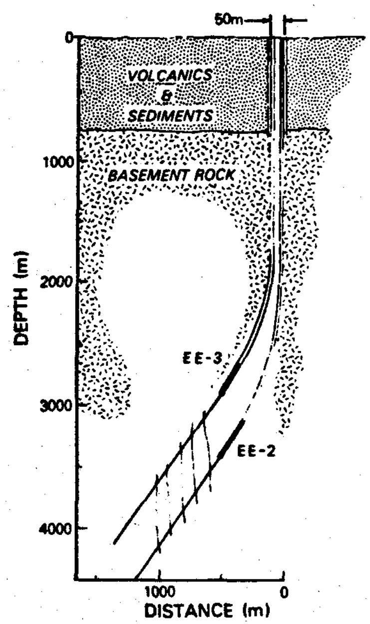

Figure 1. Elevation of Holes EE-2 and EE-3 of the Phase II reservoir system. Vertical fractures will be created from the lower Hole EE-2, extending upward to intersect Hole EE-3.

The drilling rig was skidded 46 m (150 ft) to the west in May 1980 when EE-2 was completed, and the drilling of EE-3 began. Deviation of EE-3 began at a depth of 1707 m (5600 ft) in the 31.1-cm (12-1/4-in.) hole. Completion is scheduled for summer 1981 at a depth of 4420 m (14,500 ft). The 22.2-cm (8-3/4-in.) open-hole section will begin at about 3231 m (10,600 ft), with 24.4-cm (9-5/8-in.) casing being set to that point.

LOGGING REQUIREMENTS

Directional requirements for EE-3 are quite stringent: the hole has to be very close to the same azimuthal direction as EE-2, located about 366 m (1200 ft) directly above it and at the same inclination of 35° from the vertical. In order to achieve this, the location of EE-2 had to be accurately determined by an independent survey (Wolff, 1980). In most directionally drilled wells, the driller is given a TD target and he directs the hole to hit that target, without much regard for the path by which the target is reached. But in drilling EE-3, the drilled path is also the target, as it has to parallel the previously drilled EE-2.

The temperature gradient and an accurate caliper survey for determination of straddle packer setting points are considered indispensible measurements for the successful development of the reservoir system.

The extremely difficult borehole conditions encountered in logging EE-2 are:

(1) high temperature -- approximately 335°C (635°F) BHST;
(2) deviated borehole -- 35° from vertical;
(3) depth -- drilled depth of 4660 m (15,289 ft), vertical depth of 4378 m (14,362 ft); and
(4) extremely abrasive granitic rock.

In addition, the lower half of the borehole is filled with a mixture of water, thread dope (compound used on drill pipe threads), pipe scale and cuttings, Torq Trim residue (a tri-glyceride compound used as a lubricant to reduce friction between the borehole and drill pipe), and broken, ground up, rubber protectors used around the drill pipe to prevent excessive wear on the intermediate casing string.

Inquiries were made among the commercial logging companies to locate tools that could perform this work at elevated temperatures.

Dresser-Atlas indicated they could perform the temperature and a 4-arm caliper log with their special high-temperature cable; Sperry-Sun made arrangements to operate their gyroscopic multishot directional survey tool on the Dresser-Atlas cable.

The Geoscience Instrumentation Group at Los Alamos National Laboratory also surveyed this borehole with a self-contained temperature tool on a slick-wire cable; with a three-arm caliper, and with a temperature tool on a high-temperature 7-conductor cable.

LOGGING OPERATIONS

Dresser-Atlas

Logging operations in EE-2 were conducted August 6-8, 1980 by Dresser-Atlas and Sperry-Sun. Dresser-Atlas (D-A) ran a temperature log followed by a 4-arm caliper tool on their special high-temperature cable.

The D-A continuous temperature survey was conducted going down EE-2 at a logging rate of 30 to 46 m/min. (100 to 150 ft/min). Temperature logging continued to a depth of 4531 m (14,865 ft) and was terminated at 325°C (617°F) due to a cable malfunction.

A few hundred feet of cable was cut off and an attempt was then made to log EE-2 with the D-A 3-arm caliper. A malfunction due to faulty cable again occurred at about 1829 m (6000 ft) going in the borehole and required more cable to be cut off. By this time, 305 m (1000 ft) of cable had been discarded, and D-A decided to run their 4-arm caliper tool which logs going down the borehole. After one more cable malfunction where 61 m (200 ft) more of cable was cut off, a successful run was made in the open borehole to 4285 m (14,058 ft) where the tool was overcome by heat. The bottom of the casing was detected at 3529 m (11,578 ft.). The cable itself remained usable.

Sperry-Sun

Following the D-A logging operations, Sperry-Sun conducted a gyroscopic multishot directional survey using the D-A cable. The multi-shot camera was set to take photos every 20 s. At 10-min intervals, a 3-min stop permitted recording of the precession of the gyro. The instrument was entirely self-contained, without surface readout, so cable shorts could not cause failure.

The survey was completed in two runs because of a film limitation. The first run was to 3719 m (12,200 ft), and the second, with a three-station overlap, went from 3650 to 4633 m (12,000 to 15,200 ft). The gyro package was protected by a heat shield and a heat sink; the camera and lights were battery operated.

Los Alamos Geoscience Instrumentation Group

The Geoscience Instrumentation Group (GIG) logged EE-2 with continuous temperature surveys on July 30 and August 12, 1980 to total depth (TD) of 4661 m (15,289 ft). A slight fluid invasion into the cable head was found during the second run (August 12, 1980), but this was not considered serious or detrimental to the temperature results. Part of this well was also logged on August 18, 1980 with two Kuster temperature probes using a slick line. The temperature rating of these Kuster probes was not high enough to allow logging below 4115 m (13,500 ft).

A 3-arm (independent arm readings) caliper survey was run on September 11, 1980. Temperature problems and arm retraction malfunctions were encountered with the caliper tool during the logging on two separate runs at depths of 3566 and 3901 m (11,700 and 12,800 ft). The centralizers did not properly centralize the caliper tool and would not allow it to rotate, resulting also in cable twist problems. However, this was an instrument development test and the malfunctions were not unexpected.

RESULTS

Temperature Surveys

A comparison of the temperature surveys is shown in Figure 2. The Los Alamos continuous temperature survey of August 12, 1980 compares very closely, within 1°C (2°F), to the Los Alamos

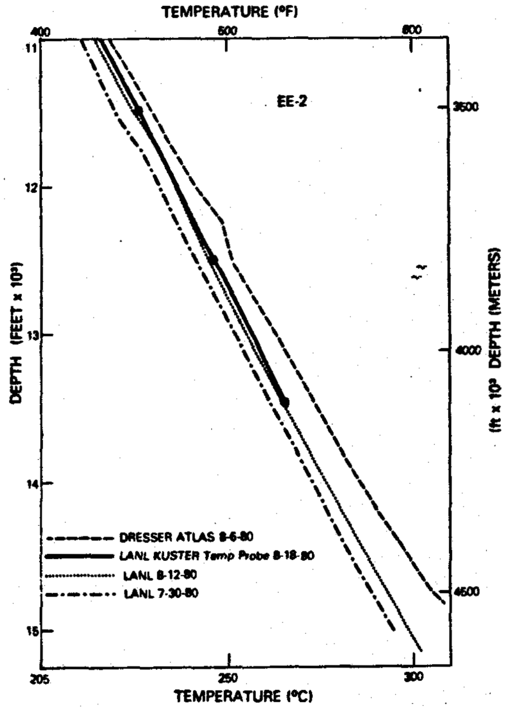

Figure 2. Comparison of temperature survey results from the Los Alamos and Dresser-Atlas logging runs.

Kuster temperature survey acquired on August 18, 1980. The thermal gradient calculated from the August 12 Los Alamos temperature survey for the bottom part of this well (3962 m to TD or 13,000 ft to TD) is 80°C/km (4.4°F/100 ft). The bottom-hole temperature was measured as 318°C (604°F) on the Los Alamos temperature survey. The Kuster survey consisted of only three points below 3354 m (11,000 ft); these points were plotted and connected with a straight line as shown in Figure 2. The first Los Alamos continuous temperature survey acquired on July 30, 1980 is 3°C (5°F) cooler than either the Los Alamos Kuster or August 12 temperature surveys. The Dresser-Atlas continuous temperature survey is 1°C (2°F) warmer at 3354 m (11,000 ft) than either the Los Alamos Kuster or August 12 temperature surveys and is 6°C (11°F) warmer at 4500 m (14,760 ft) than the Los Alamos August 12 temperature survey.

The Los Alamos temperature probe is a thermister tool with a sensor composed of glass, while the Dresser-Atlas temperature probe has a platinum resistor sensor. Both tools are very stable. The difference between the slope and values of the Los Alamos and the Dresser-Atlas temperature profiles is probably due to temperature effects on the Dresser-Atlas cable which failed at 4531 m (14,865 ft).

A temperature anomaly (increase in temperature above the projected gradient) occurs at 3660 m (12,000 ft) on both Los Alamos temperature surveys and also occurs at 3720 m (12,200 ft) on the Dresser-Atlas temperature survey. At the present time no explanation can be given for this temperature anomaly. A depth error between the Dresser-Atlas survey and Los Alamos surveys is possible, but a 60 m (200 ft) error is a rather large difference.

Caliper Surveys

No comparison can be made between the Dresser-Atlas caliper survey and the Los Alamos caliper survey. The first Los Alamos caliper survey log (Figure 3), shows the single arm responses and the average response of this 3-arm caliper tool. This plot exhibits spurious electrical noise on arm 1, improper or no centralization between the 3 arms, and problems with arms 1 and 2 not fully extending. A second caliper survey was run on the same date with similar results. The average response of this caliper tool on both runs appears reasonable but data obtained from the single arm responses are not reliable because of the problems with arm extension and centralization.

The Dresser-Atlas caliper probe is a 4-arm bow spring tool that measures the average response. The caliper survey exhibited four intervals where it measured a borehole diameter considerably less than the drill bit diameter of 22.2 cm (8-3/4 in.). These intervals are 3720 to 3817 m (12,200 to 12,520 ft), 3840 to 3863 m (12,600 to 12,670 ft), 4003 to 4034 m (13,130 to 13,230 ft), and 4216 to 4286 m (13,830 to 14,059 ft). The 3720 to 3817 m (12,200 to 12,520-ft) interval is shown in Figure 4. This small borehole size measurement can be attributed to caliper tool malfunction. This malfunction is due either to the electronics of the tool being affected by high temperature, or the bow springs being affected by the combination of deviated hole and high temperature, or both. It is interesting to point out though that the first anomalous caliper region (3720 to 3817 m, 12,200 to 12,520 ft) occurs where the temperature anomaly previously discussed also occurs. This caliper tool failed at 4286 m (14,059 ft) due to heat. The Dresser-Atlas caliper survey is questionable and cannot be relied upon. Single arm responses were not available to evaluate the average response of this

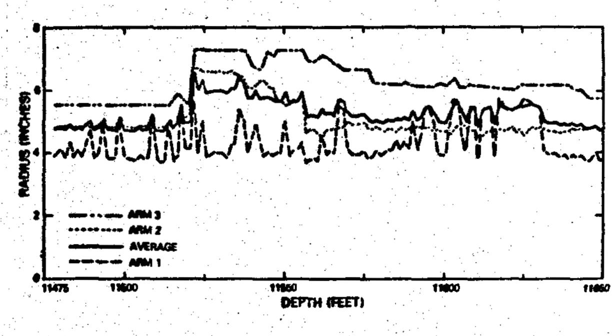

Figure 3. Results of the Los Alamos 3-arm (independent) caliper survey on September 11, 1980.

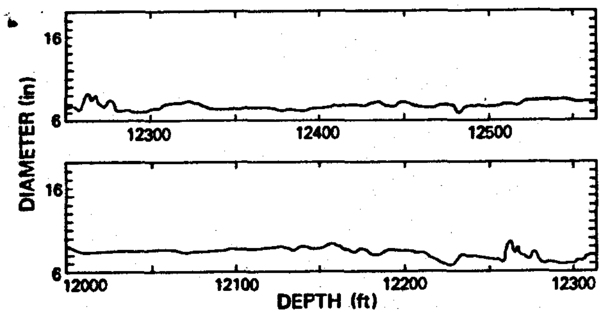

Figure 4. Results of Dresser-Atlas 4-arm (average response) caliper survey on August 7, 1980.

tool. These would have been helpful in evaluating the anomalous intervals.

Directional Survey

The Sperry-Sun self-contained, gyroscopic multishot directional survey was completed in two runs to the bottom of EE-2 without any problems. This survey compares extremely well with the single shot survey data as shown in Figure 5. These data are considered reliable and borehole EE-3 is being directionally drilled using this information. A smooth directional and inclination survey occurs in the interval where the temperature and caliper anomalies previously discussed also occur.

SUMMARY

The minimum logging requirements for EE-2 were a continuous temperature survey, a caliper survey, and a multishot directional survey.

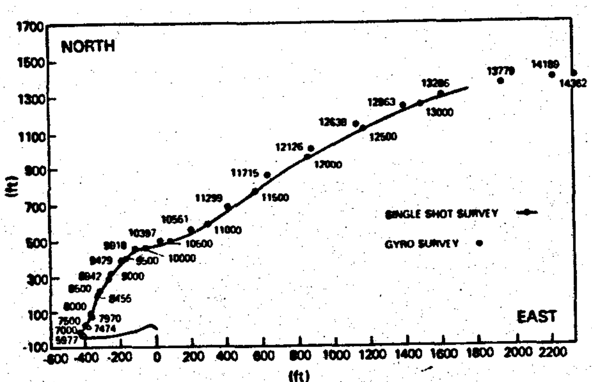

Figure 5. Combined plot of Sperry-Sun gyroscopic survey results taken on August 8, 1980, with the Eastman-Whipstock single-shot survey results taken during drilling. All depths are true vertical.

Success was obtained in continuous temperature surveys as shown in Figure 2 and in the multishot directional survey as shown in Figure 5. These data are considered reliable and are being used in the reservoir engineering design of the commercial-sized system.

Reliable caliper data of the open-hole section of EE-2 are needed to set the open hole straddle packers for the hydraulic fracturing operations necessary to connect EE-2 and EE-3, in the HDR reservoir. However, the caliper data obtained are not considered reliable, probably due to the high temperature, depth, and inclination of EE-2. Upgrading of the caliper tools is being performed to acquire the needed data.

Other log data such as a gamma-ray, density, neutron, etc. are needed to characterize the geology around the borehole and form a lithologic log with the aid of cuttings and cores. At the present time, and without a large amount of cooling, additional logging data cannot be easily acquired from this well because of the temperature limitation of existing commercial logging tools.

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REFERENCES

Brittenham, T. C., Neudecker, J. W., Rowley, J. C., and Williams, R. E., 1980, Hot, Abrasive Formations Test New Drilling Equipment: World Oil, October, p. 95-102.

Wolff, C. J. M., DeWardt, J. P., 1980, Borehole Position Uncertainty, Analysis of Measuring Methods and Derivation of Systematic Error Model, SPE 9223, 55th Annual Fall Conference, Dallas, Texas.