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Drilling of Hot-Dry-Rock Geothermal-Energy Extraction Well EE-3

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DRILLING OF HOT DRY ROCK GEOTHERMAL ENERGY EXTRACTION WELL EE-3

by

John C. Rowley and Richard S. Carden

ABSTRACT

The drilling of EE-3, the production well of the hot dry rock geothermal energy-extraction engineering system at the Fenton Hill site, was finished August 25, 1981. EE-3 was designed to be directionally drilled in the inclined reservoir section to be parallel to and spaced vertically 370 m (1200 ft) above EE-2, the injection well, which was drilled at 35° to the vertical. The reservoir heat transfer area will be formed by creating and extending several vertical parallel hydraulic fractures from EE-2 to EE-3. EE-3 required precision directional drilling because the borehole trajectory had to be drilled within specified tolerances with respect to EE-2. Well EE-2 was drilled with a packed (stiff) bottom-hole assembly that held the 35° inclination, but permitted the borehole to turn in azimuth. Directional drilling experience in EE-2 provided the basis to optimize the directional trajectory of EE-3 to within the desired tolerances.

The EE-3 well was drilled into hot granite reservoir rock to total depth at 370 m (1200 ft) parallel and above EE-2 at a measured (drill-string) depth of 4.25 km (13 933 ft), with a maximum lateral deviation of about 60 m (180 ft). A bottom-hole static temperature of 280°C (550°F) is estimated.

Two severe drill-pipe twist-offs extended the drilling time of EE-3 to 461 days. These, and other drilling problems, are recorded and solution approaches are discussed. Drilling costs of EE-2/EE-3 are shown to be comparable to commercial drilling of hydrothermal wells and to the US Department of Energy sponsored geothermal projects when these cost trends are extrapolated to 4.5-km (15 000-ft) depths.

I. INTRODUCTION

The high-precision, controlled-trajectory drilling of EE-3 was dictated by the requirements of the reservoir. The borehole path was based upon the survey results, i.e., magnetic single-shot and gyro multishot, previously obtained for the 22.2-cm (8-3/4-in.)-diam drilled portion of EE-2. This ∿1000-m (3000-ft) length of borehole was drilled at an inclination of 35° and was directionally oriented into the northeast quadrant. This alignment was chosen to place the EE-2 and EE-3 boreholes approximately normal to the predicted northwest-southeast direction of the planes of the hydraulic fractures of the previous pair of hot dry rock (HDR) wells (GT-2/EE-1).[1] The EE-2 borehole was drilled by stiff or packed-hole holding assemblies that held the inclination angle of the borehole but allowed the azimuth to drift, or "walk," in accordance with the interaction of bit and bottom-hole drilling assembly with the rock.

The wellbore directional-drilling parameters set as targets for the reservoir portion of EE-3 were

- 370 m ±15 m (1200 ±50 ft) vertically above EE-2,
- ±30 m (±100 ft) lateral deviations from the horizontal projection of the EE-2 trajectory, and
- total depth (TD) at true vertical depth (TVD) of 4030 km (13 230 ft); directly above the TD of the EE-2 wellbore at a TVD of 4398 m (14 405 ft).

These objectives were met within practical drilling limits and resource constraints. The maximum deviations observed were a slightly greater vertical spacing of 400 m (1300 ft) over the upper few meters of the reservoir, decreasing to within 370 m ±15 m (1200 ±50 ft) below. The widest lateral deviation occurred at EE-3 TD, 4.247 km (13 933 ft) measured depth (MD)*, or 3.977 km (13 048 ft) TVD, where the wellbore EE-3 had drifted to the north slightly and indicated a position displaced about 60 m (180 ft) north as evaluated from the magnetic single-shot survey data. The final relation of EE-3 above EE-2 is depicted in Figs. 1 and 2, which also illustrate the magnitudes of the deviations from the targets that were achieved with the controlled-trajectory drilling of EE-3.

The drilling plans for EE-3 closely followed those for EE-2, with modifications and improvements as learned from previous drilling operations and those changes dictated by the directional control required to place EE-3 above the reservoir portion of EE-2. This plan, in summary, follows.

*All depths recorded are measured along the drillstring from the elevation of the Kelly Bushing (KB), unless otherwise noted. The EE-3 KB was 8.2 m (27 ft) above ground level.

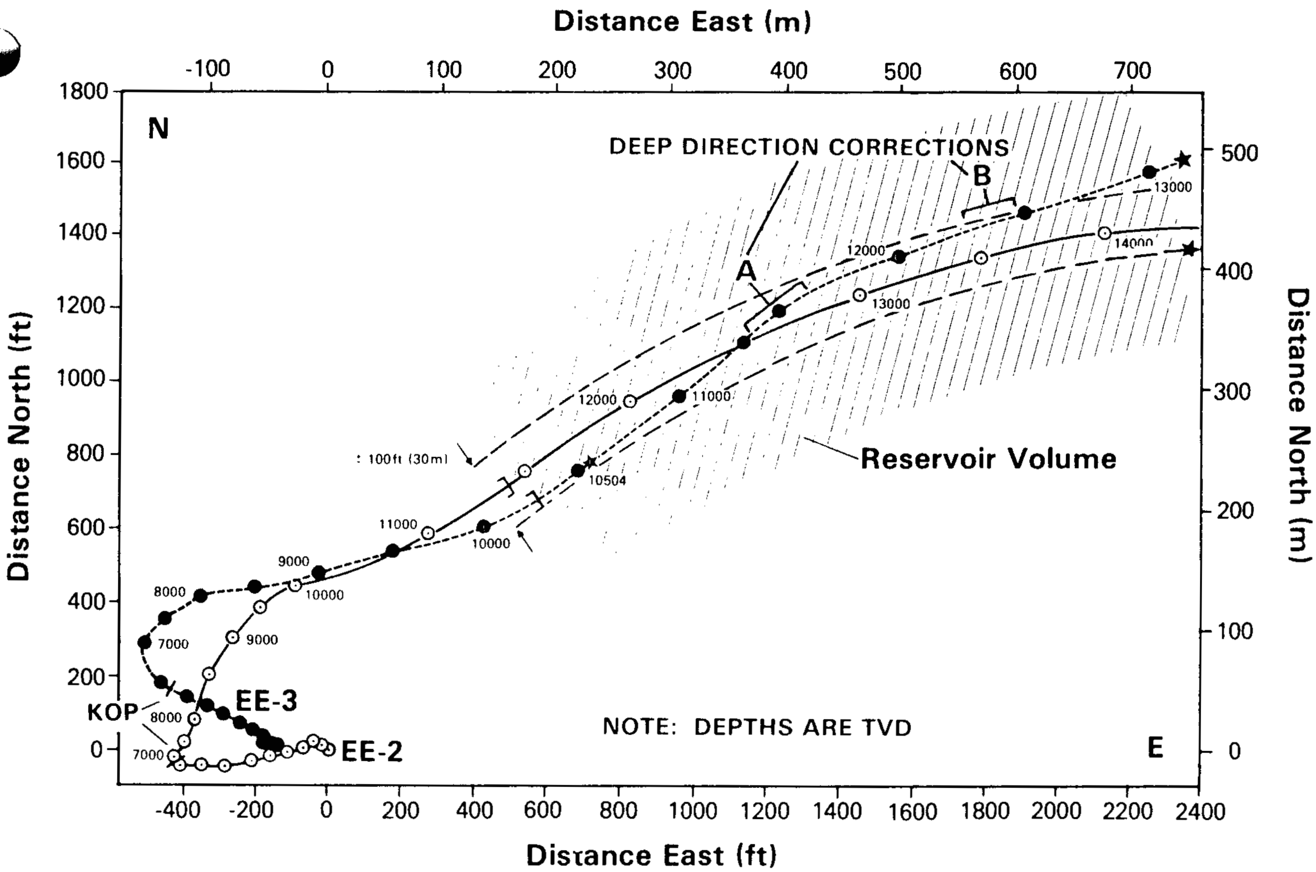

Fig. 1.
Plan view of EE-2/EE-3 well trajectories and tolerance band for EE-3 directional drilling.

(1) Drill the 800-m (2500-ft) section of volcanic and sedimentary rocks as in the EE-2 plan,[2] but drill the lost-circulation zones without returns as far as feasible and run and cement the 34.0-cm (13-3/8-in.) casing about 50 m (150 ft) into the granite. This casing string would be tensioned after cementing so as to guard against compressive failure of the casing upon heat up during production.

(2) The kickoff point (KOP) for directional drilling of the 31.1-cm (12-1/4-in.)-diam borehole was to be at about 2000-m (6500-ft) depth where the inclination was to be raised and the azimuthal angle started to be directed into the northeast quadrant.

(3) Directional drilling of the 31.1-cm (12-1/4-in.)-diam hole would continue until an inclination angle of 35° $\pm$1° was established and an azimuth angle of N55° $\pm$5°E, at a MD of about 3124 m (10 350 ft), [a TVD of 3109 m (10 200 ft)] at a vertical distance of 370 $\pm$15 m (1200 50 ft) directly above

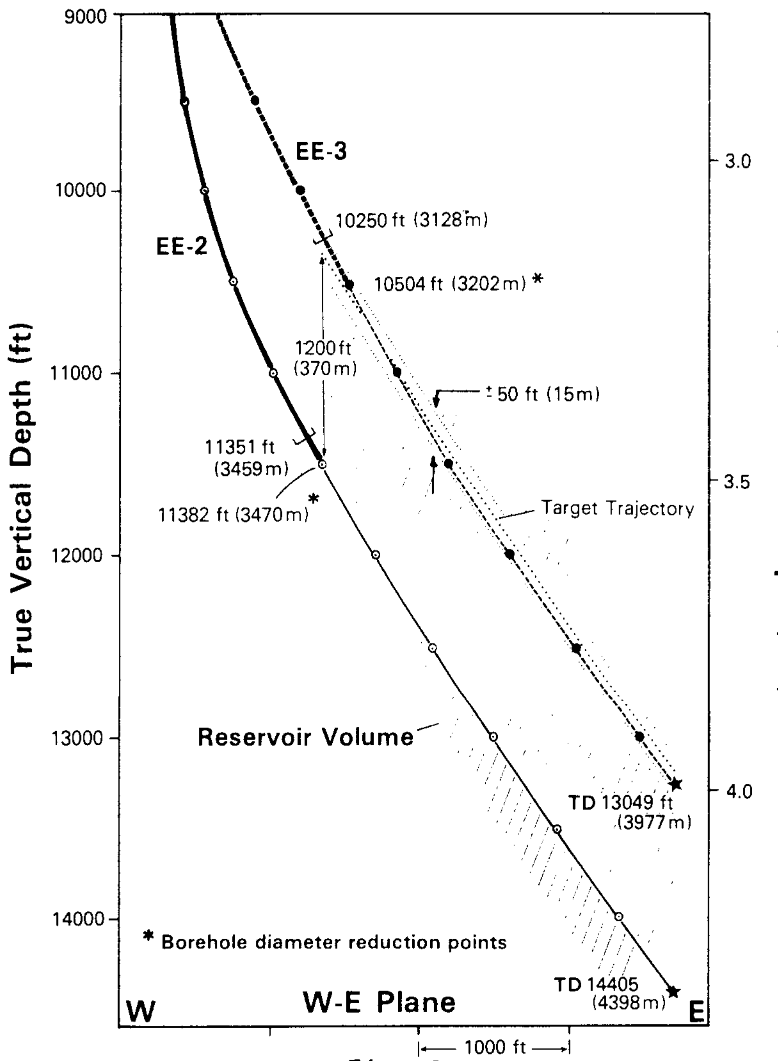

Fig. 2.
EE-2 and EE-3 trajectories projected into east-west vertical plane showing EE-3 target inclination and vertical-separation target tolerance.

the EE-2 hole diameter reduction point. This would place the EE-3 wellbore in such a position and orientation so that the tangent to the trajectory would be a vector parallel to the tangent to the EE-2 wellbore trajectory 370 m (1200 ft) below.

(4) Drill a 24.8-cm (9-7/8-in.)-diam transition hole about 6.1 m (20 ft) long.

(5) Drill reduced hole diameter with a 22.2-cm (8-3/4-in.)-diam bit, and use packed-hole (stiff) inclination-angle-holding assemblies.

(6) Take single-shot magnetic surveys every 20 m (60 ft) and apply directional (azimuthal) corrections by use of high-temperature turbodrill runs as

required to maintain the EE-3 borehole path parallel to EE-2 borehole to within the ±30-m (±100-ft) horizontal tolerances as listed above, and drill to TD.

(7) The well would be cased with 24.4-cm (9-5/8-in.)-o.d. production casing to the bottom of the 31.1-cm (12-1/4-in.) hole after the drilling had reached the planned TD of 4.03 km (13 230 ft) TVD or a TD of about 4.4-km (14 400 ft) MD. This production casing string would be run, cemented, and tensioned to prevent excessive thermal growths and stresses at the wellhead during production.

This plan was completed in all its essential features in 461 days. Discussion of the earlier problems with the EE-2 drilling can be found in Refs. 3, 4, and 5. The early part of the EE-3 directional drilling operations are reviewed in Refs. 6 and 7, and the drilling-fluid system established at Fenton Hill for the drilling of EE-2 and used for EE-3 is documented in Ref. 8.

II. CHRONOLOGY OF DRILLING EE-3

A. Drilling through the Volcanics and Sediments

The history of the drilling of well EE-3 is summarized in Fig. 3, a daily drilling log is included as Appendix A, and the detailed bit record is recorded in Appendix B. Depth progress is plotted vs days of drilling from May 21, 1980, to the rig release date of August 25, 1981, a total of 461 days.

The drill rig was skidded from the EE-2 site 50 m (165 ft) to the west without lowering the derrick. The 76.2-cm (30-in.)-diam conductor pipe and the cellar had been previously emplaced. A new drilling-fluid reserve pit, to be used in conjunction with the previously excavated EE-1 and EE-2 reserve pit, and an extension of the drill pad had been prepared before skidding the rig. The bottom-hole drilling assembly with a 62.4-cm (26-in.)-diam milled-tooth bit was picked up on May 21 and the hole was spudded on May 22, 1980. Drilling was performed in volcanic and sedimentary rocks with 62.4-cm (26-in.)-diam bits to a depth of 577 m (1894 ft) without serious lost-circulation problems, but at this depth, loss of drilling-fluid circulation was complete. Two attempts were made to cement-off the lost-circulation zone by pumping cement plugs into the hole using 500 sacks of thixotropic cement. The hole was drilled through the cemented zone after the first cementing attempt, and circulation was lost again. After the second cement-plug attempt, the hole was drilled into the cement to 541 m (1775 ft). Considerable sloughing of the hole walls and bridging of the hole above the lost-circulation problem were experienced, and it was necessary to set the 50.8-cm (20-in.)-diam surface casing in order to continue drilling.

Fill that was in the bottom of the hole prevented the casing from reaching the bottom, and the casing was set with the cementing shoe at a 481-m (1580-ft) depth. A slurry containing 2400 sacks of cement was pumped into the annulus behind the 50.8-cm (20-in.) casing without filling the annulus. Additional cement slurry with 650 sacks of cement was pumped into the annulus from the surface, which filled it to the surface.

After waiting for the cement to harden, the cement was drilled out with a 44.5-cm (17-1/2-in.)-diam milled-tooth bit. Drilling was started again below the cement with a 44.5-cm (17-1/2-in.) bit, and circulation was lost again at 567 m (1860 ft). One attempt was made to cement up the lost circulation with a massive amount of cement (2500 sacks). This was unsuccessful. It was decided to drill on into the granitic formations without return of the drilling fluid. Drilling without returns was quite expensive as the water supply from La Cueva, 7.5 km (4.5 miles) away, was exhausted, and most of the water for this operation was hauled from Los Alamos, a distance of 45 km (27 miles) over mountainous roads. This also caused some delays because the usage rate exceeded the practical hauling rate. The granite was encountered at 732 m (2404 ft), and the drilling continued to 783 m (2567 ft), some 51 m (150 ft) into the crystalline rock.

A 34.0-cm (13-3/8-in.)-o.d. casing was run into the hole and cemented in two stages. The first stage consisted of a cement slurry containing 200 sacks of cement to bond the bottom of the casing to the granitic formation for about 45 m (150 ft). After this cement was set, the casing was tensioned with casing jacks to a load of 373 x 10^4N (725 000 lb_f); an axial stretch of the casing of 48 cm (19 in.) was recorded at the wellhead. The tensioning was done to prevent the occurrence of excessive compression loads in the 34.0-cm (13-3/8-in.)-o.d. casing when it is heated by hot fluid production with the completion of the EE-2/EE-3 reservoir system. A considerable delay (5 days) was incurred while waiting for suitable casing jacks to arrive. Next the casing was cemented from 428 m (1403 ft) to the surface through a cementing stage collar and an expandable external casing packer (so-called DV tool) that had been included in the casing string at that depth. Drilling operations had been underway for 39 days, as the rigging up of flow lines, riser pipe, blowout-preventer (BOP) stack and associated hardware was accomplished in

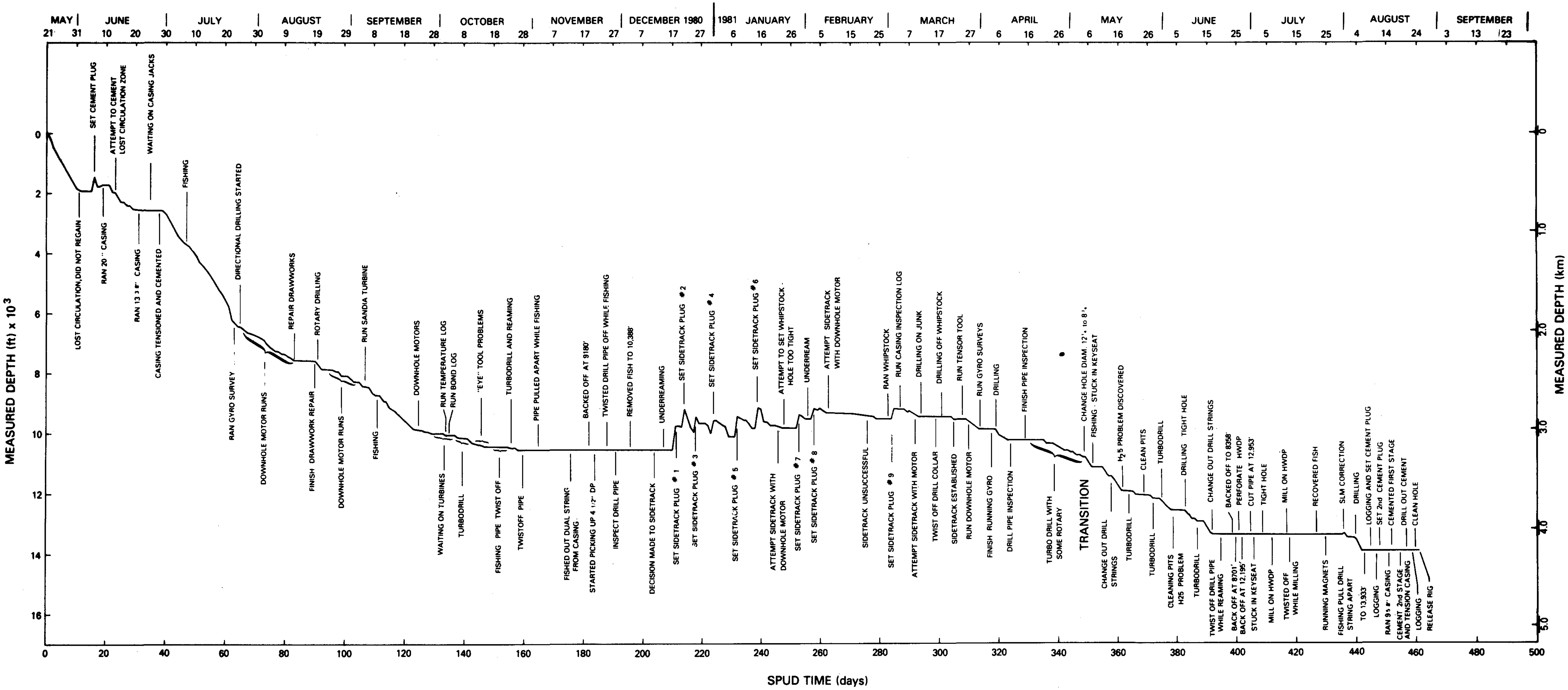

Fig. 3.
EE-3 drilling chronology.

preparation for drilling out cement in the 34-cm (13-3/8-in.)-o.d. casing. The casing shoe was located at a depth of 778 m (2552 ft) and the bottom of the 44.5-cm (17-1/2 in.)-diam hole at 782 m (2567 ft).

B. Drilling to the KOP

The first 31.1-cm (12-1/4-in.)-diam drilling assembly used a milled-tooth bit to drill out the cementing hardware (cementing sleeve, float collar, plugs and shoe) and the cement below the shoe. The first 31.1-cm (12-1/4-in.)-diam carbide insert button bit and bottom-hole assembly (BHA) was run in the hole and rotated very slowly (40 rpm) with a low load on bit, 1.3×10^4 N (30 000 lb_f), to avoid casing and cement damage. This precaution was continued until the top reamer of the BHA was below the 34.1-cm (13-3/8-in.)-o.d. casing shoe.

Rotary drilling of the 31.1-cm (12-1/4-in.)-diam hole continued using a variety of tungsten-carbide-insert (TCI) button bits to a depth of 1964 m (6444 ft). This drilling sequence was plagued by occasional washouts of the drill collars and two short fishing jobs but was the least troublesome of any of the drilling of EE-2 or EE-3. At this depth the hole had an inclination of 10° to the vertical and the azimuthal direction was trending in a northwest direction (N58°W) at that depth. The wellbore had to be turned to a northeasterly direction in order to drill in the proper direction relative to the trajectory of hole EE-2. This portion of the hole was surveyed approximately every 20 m (60 ft). The instantaneous drilling rate varied from 1.2 to 6.9 m/h (4.0 to 20.0 ft/h). Twelve bits were used in 17 bit runs. An inspection of the BHA components, boxes, and pin ends of collars especially, was carried out. A gyro survey of the hole trajectory through the 34.0-cm (13-3/8-in.)-o.d. casing was run on day 63 with the bottom of the hole at 1930 m (6334 ft) to check the hole trajectory in the cased section. The survey showed an inclination of 0.83° and an azimuth of N40°W at 762-m (2500-ft) depth (just above the cementing shoe). No severe doglegs* were detected, the maximum being about 1°/100 ft at 144-m (500-ft) depth. Drilling and related operations for this portion of the hole took 26 days, and the stage was set for the first directional drilling.

*The term dogleg severity (DLS) refers to the curvature of the borehole trajectory, and is usually measured in degrees/30 m (degs/100 ft).

C. Directional Drilling to the Borehole Diameter Transition

This portion of the drilling program was intended to turn the borehole to the east, about 80° east from north (N80°E), and raise the inclination to 35°. Two major problems significantly delayed this segment of the drilling program: (1) a twist-off of the 12.7-cm (5-in.) drill pipe occurred at 3209-m (10 578-ft) depth. This required an extended unsuccessful fishing operation and (2) finally required a problem-plagued sidetracking of the hole at 2878-m (9444-ft) depth.

The initial borehole-trajectory elements were 10° N63°W (10° inclination and an azimuth heading of 63° west from north) at a depth of 1920 m (6431 ft). The initial two directional drilling runs below the 1694-m (6444-ft) KOP depth were attempted using magnetic single-shot orienting tools to orient the downhole motor direction. The intention was to rotate the azimuth of the hole and build angle only slightly. However, a sharp angle-build was experienced, increasing to 14°, with little azimuth change. After three directional drilling runs with a positive displacement motor (PDM) (Baker Service Tools), the inclination had increased sharply to 14-3/4° from the vertical, but the azimuth, at N42°W was not changing rapidly enough for the 81 m (266 ft) of depth and four days of effort. To monitor the orientation setting and progress of the downhole drilling motors, a continuous-readout steering tool, the Scientific Drilling Control (EYE) steering tool, was used on most subsequent directional runs.

The next 13 days were spent changing the hole azimuth to N62-1/2°E over a drilled section to 2280 m (7482 ft). A total of 10 directional drilling runs was performed during this trajectory-control sequence and the inclination had dropped to 8-3/4°. A rotary reaming assembly was run in the hole to bring the gauge back to 31.1 cm (12-1/4 in.) and drilling was suspended at a depth of 2299 m (7542 ft) to provide for a routine inspection of the drill string. Five days were required to conduct the inspection. During this time the main drive-shaft on the rig draw-works was replaced (a severe fatigue crack had developed) and other components of the hoisting equipment were inspected.

Rotary drilling began again on day 91 of drilling operations with the plan to use a building BHA to increase the inclination while monitoring the azimuthal drift of the hole. This drilling started at 2300 m (7542 ft) and was continued to 2390 m (7840 ft) with another sharp inclination increase from 7° to 14-1/4°. However, the azimuth angle rotated to the north, from N83°E to

N46°E-- a change of 37° in 90 m (300 ft). Therefore, directional drilling with downhole motors was resumed. Problems with the EYE steering tool were encountered and test drilling of a new high-temperature Dyna-Drill 17.8-cm (7-in.)-diam turbine was performed but steering-tool problems restricted the test run to about 3 m (10 ft).

A sequence of eight motor runs was performed and the hole trajectory was corrected to a survey reading of 17-1/4°N88°E at a depth of 2562 m (8407 ft) in eleven days. Two more Dyna-Drill 17.8-cm (7-in.)-diam turbine tests were performed at the end of this directional drilling sequence. The depth was 2576 m (8453 ft).

A series of nine rotary drilling runs with either hold BHA or moderate-build characteristics was then completed to a depth of 3002 m (9850 ft) and the trajectory elements had been changed to 25-1/2°N67°E. The inclination angle was successfully building, but north drift was still occurring. Lack of availability of downhole motors dictated continuation of rotary drilling for three more bit runs. A washout in the box-end thread of a drill collar occurred at 2690-m (8827-ft) depth on day 111. This rotary drilling sequence ended on day 124.

Directional drilling was started again when a PDM downhole-motor run was attempted on days 125 and 131, but it was evident that the temperatures were too high for the elastomer components of the motors so it was decided to initiate use of the 19.7-cm (7-3/4-in.)-diam Maurer Engineering Inc. (MEI)* turbodrills.

The original reserve pit had filled with cuttings by this time and required dredging of the reserve pit with a dragline and hauling of the solids to a nearby dump. Drilling operations continued using the smaller reserve pit adjacent to the drill rig. (This was the new westernmost pit and too small for extended effective cooling and cuttings settling.) A fluid-loss region encountered at about 3025 m (9924 ft) complicated the drilling fluid problems. Dredging continued for 11 days. The rotary drilling sequence was continued to 3653 m (10 017 ft) and trajectory survey results of 24° N67°E were determined at 3032 m (9946 ft).

*Maurer Engineering, Inc. of Houston, Texas, developer of the special turbodrills for directional drilling.

A cement-bond log was run in the 34.0-cm (13-3/8-in.)-diam casing on day 135 to evaluate the extent of bonding of the cement to that casing string. The bottom 70 m (200 ft) showed good bond; the 430 to 560 m (1400 to 1900 ft) showed no bonding, and the remainder indicated partial bonding.

On day 138, directional drilling was initiated with the two Los Alamos MEI 19.7-cm (7-3/4-in.)-diam high-temperature-rated turbodrills. The objective was to build inclination angle and to hold or increase the westerly trend in the trajectory. The use of high-temperature MEI turbines was indicated by the loss in performance of the PDMs and due to the bottom-hole (static) temperature of 200°C (400°F). Alternate directional drilling runs and rotary reaming and inclination building runs were performed.

A reaming and build assembly, run on day 143, appeared to be building too rapidly, so bit weight was reduced, but apparently too rapidly, which caused the inclination to drop sharply. Figure 4 shows the inclination angle behavior in this section of the hole. During subsequent turbodrill runs this drop in angle was rebuilt. On day 145, the EYE steering tool jammed and was left in the BHA. When inspected on the rig floor it was discovered that the mule-shoe latch-in on the steering tool was jammed 170° away from the key pin in the orienting sub. This condition was due to wear of the components and was not detected because the seating procedures (multiple engagement and reengagement of the seating) are performed routinely by the wireline operator. That procedure was being followed and monitored especially closely. The geometry of the BHA made it extremely unlikely that this misorientation could occur even once, let alone repeatedly. However, the consequences were that two sharp downward dips in the inclination were introduced into the EE-3 trajectory. This is illustrated in Fig. 4. Extremely tight-hole conditions were experienced upon reaming to bottom and the first reaming assembly with a six-point near-bit reamer had to be changed out for a three-point near-bit assembly. When very high torques of the BHA occurred, a survey at 3128 m (10 262 ft) indicated that the trajectory had the elements 26-3/4° N68°E confirming that the second loss of inclination had occurred.

Reaming continued with a more-limber or less severe build-assembly at 3157-m (10 357-ft) depth on day 150 when a twist-off of the 12.7-cm (5-in.)-diam drill pipe occurred. A fishing operation was initiated that retrieved the free pipe, 75 stands plus two joints of 19.6 lb/ft grade E drill pipe. The fish was successfully grappled. Indications were that the break

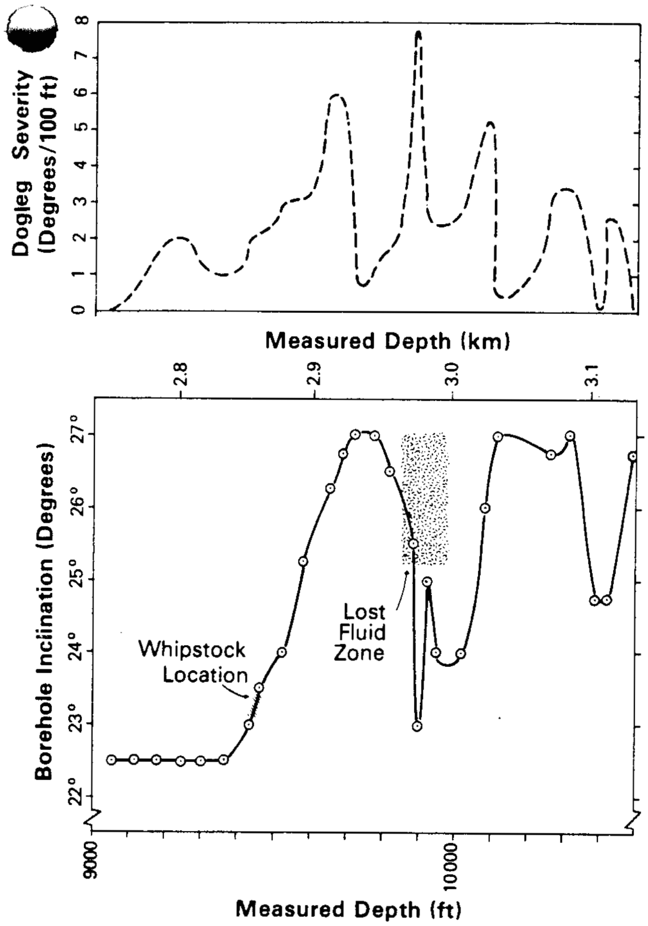

Fig. 4.
Inclination and dogleg severity for 3.0- to 3.2-km depth interval in EE-3.

was in pipe body about 2/3 m (2 ft) below a coupling, and that the lowermost steel drill collar in the BHA had parted in the threads of the pin. Four days were spent grappling and loosening the fish, but on day 154 following the successful fishing, the hole was reamed to a depth of 3175 m (10 417 ft) where a survey yielded results of 24-3/4° N66°E and verified again a considerable drop in inclination. Directional drilling continued in an effort to obtain the desired inclination and more easterly trend. MEI turbodrill runs were alternated with reaming assemblies. Very tight-hole conditions continued to plague the directional drilling operations, and on day 159, a second drill-pipe twist-off occurred at about 2350 m (7070 ft). The BHA had fallen to bottom and the break was very jagged, (Fig. 5) and about 2/3 to 1 m (2 to 3 ft) below the coupling.

D. Fishing and Sidetracking

The drilling of EE-3 was interrupted for 44 days (from day 160 to day 204) by a difficult fishing operation that did not retrieve the BHA, and the hole had to be sidetracked. The sidetracking was finally achieved using a permanent, cemented-in, whipstock.

Because the twist-off had occurred while reaming with the bit off bottom, it was assumed that the fish had fallen to the bottom. This might imply that there could be considerable bent or cork-screw buckled drill pipe above the BHA and that the BHA might be badly jammed into the hole. However, free-point surveys showed that the uppermost reamer was the tight spot so back-off shots were attempted just above this point. A back off on day 163 succeeded in parting the fish by a break in the middle of the drilling jars.

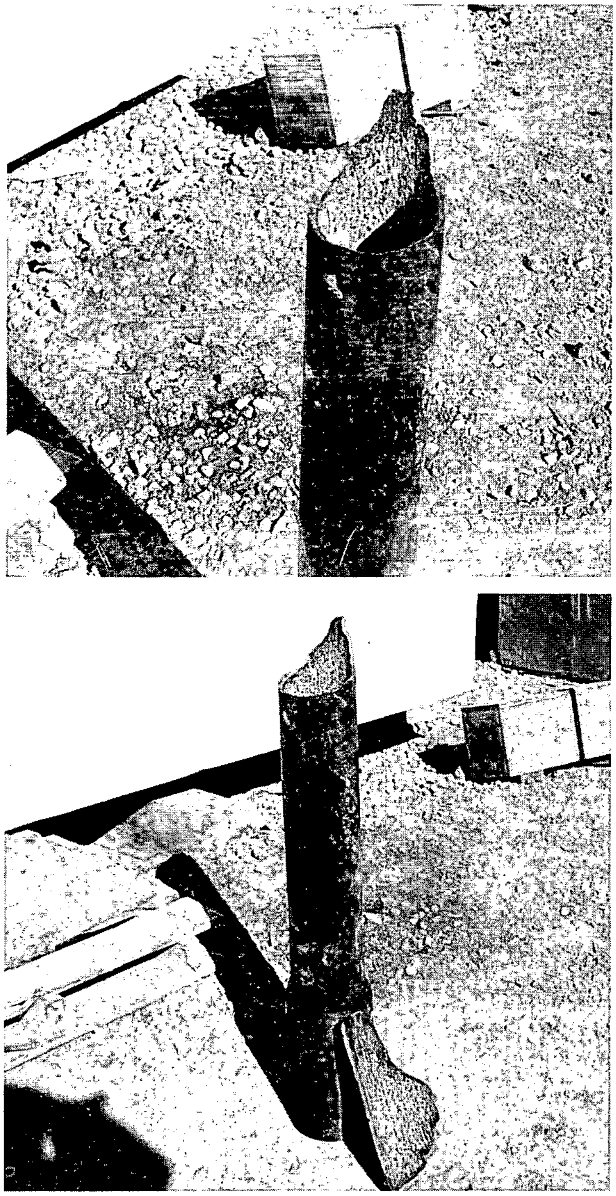

Fig. 5.
Views of inside surface of 12.3-cm (5-in.) drill pipe showing severe corrosion pitting and nature of fracture. Box end of joint shown.

The fish remaining had nine joints of heavy-weight drill pipe (HWDP) below it. A back-off shot unscrewed the HWDP but left the bit, bit reamer, stabilizer, and drill collars in the hole. While jarring and pulling out this fish (day 167), the drill-pipe string parted and the rebounding string separated the Kelly and damaged the swivel, cables, and hoisting block and then fell back down into the hole.

Subsequent tagging and a free-point survey indicated that the top section of the pipe had gone down beside the bottom section of drill pipe inside the 34.0-cm (13-3/8-in.)-o.d. casing. This double-parked situation caused the succeeding fishing operations to be very difficult and delicate. Back-off and jarring on the double-parked fish (drill string) and the lower string continued, until by attrition and nine days of judicious jarring, the shorter, double-parked fish was loosened and removed on day 176.

Attention was then directed once again to retrieving the BHA fish located on bottom with the top of the string connected to it at 720 m (2362 ft). Junk jammed on top of the fish, or an obstruction on the top box connection, required that the pipe be cut off with a special external cutting tool. Then the drill pipe had to be backed off to a depth of 2774 m (9100 ft) to clear the hole of badly bent pipe. All joints of the 12.7 cm (5 in.) pipe were being sent off to the rig contractor (Brinkerhoff-Signal Drilling Co.) in

Farmington, New Mexico, and a new string of 11.4-cm (4-1/2-in.)-diam drill pipe was rented and started arriving on site. This decision to change out the drill string was based upon the nature of the pipe failure (twist-off). The break was very jagged with numerous extremely deep corrosion pits evident on the inside surface of the pipe. Figure 5 shows this corrosion pitting near the fractured end of the drill pipe. An additional factor was the long hours (greater than 3000) of heavy drilling accumulated during the previous drilling of EE-2. On day 183 the 34.0-cm (13-3/8-in.)-o.d. casing was inspected with a 64 arm-caliper casing inspection tool to assess whether the fishing (jarring especially) had caused any damage. A 31.1-cm (12-1/4-in.)-diam swedge was also run through the casing to assure that obstructions were not present. No significant damage or wear was detected. More new 11.4-cm (4-1/2-in.)-diam drill pipe was delivered to the site to be used for the remainder of the fishing operation and subsequent drilling. The No. 1 drilling fluid-circulation pump was replaced.

Fishing operations continued with the new 11.4-cm (4-1/2-in.) drill string. A screw-in sub was attached to the fish at 2774 m (9100 ft) but jarring would not loosen the fish. While attempting to torque up the screw-in sub, the new 4-1/2-in. drill pipe twisted off in a connection at about 1020 m (3350 ft). The failure was due to a cracked thread in a pin. Because the fish would not move, a deep back off at 3094 m (10 150 ft), above the collars, was undertaken on day 189.

The hook below the main traveling block was replaced because it was damaged during the Kelly-rebound episode. The 11.4-cm (4-1/2-in.) pipe that had twisted off had to be straightened and inspected. Fishing continued with a fishing assembly. Jarring moved the fish upward but the jars gave out, because of the elevated temperatures. While attempting to back-off the top of the collar on the fish with torque on the string, the fish broke off below the collars. When the upper part of the fish was on the rig floor, it was found that the jars had twisted off leaving about 42.7 m (140 ft) of BHA in the hole with the top at a depth of 3162 m (10 375 ft). Fishing operations consisted of attempts to grapple the broken-off end of the jars at the top of the fish. Finally, on day 203, a lead impression block was run in on top of the fish and confirmed that the 9.5-cm (3-3/4-in.)-diam mandrel portion of the jars, a hardened chromium-steel shaft, was lying over against the borehole wall.

Following two futile days of attempting to grapple the body of the jars and failure to hook the fish, it was decided to start sidetracking operations. It was judged at this point that further grappling or milling on the fish had a low probability of success, and the fishing operations were suspended. The two fishing episodes consumed 4, and 44 days respectively, a total of 48 days.

The sidetracking of the fish was planned to be performed using techniques similar to those used previously in the successful sidetracking of HDR well GT-2.[10] Underreaming (opening up of the borehole diameter) and placement of cement plugs were the approaches used. This technique required the use of downhole motors with side force applied to the bit. This in turn is optimized by large axial thrust (bit load) and slow penetration rates to force the bit against and to cut a groove into the side-wall of the borehole or underreamed section. Time drilling (controlled penetration rate with low bit loads) is usually necessary because cement plugs drill rapidly at the low bit weights developed with the higher-rpm drilling motors. Further, time drilling is not practical with the high-temperature turbodrills due to the runaway tendency at low torque and low bit load. The excellent rpm control of the PDMs is suited to this operation, but the elastomer stator temperature limit requires that depths in EE-3 be restricted to temperatures below 200°C (400°F), or less than 3.0-km (10 000-ft) depth (see Fig. 6).

To evaluate the possible locations for underreaming, a caliper log was run (by Dresser Atlas) on day 204, over the 2958- to 3154-m (8500- to 10 348-ft)-depth interval. A zone at 2975 to 2979 m (9760 to 9775 ft) was selected to underream. The Tri-State Oil Tool Company underreamer (a three-arm tool, with TCI buttons on the cones and especially designed for granite) was used. The tool was equipped to underream the wellbore from 31.1-cm (12-1/4-in.)-diam to 40.6-cm (16-in.)-diam. The initial attempt stuck the underreamer and lost two cones. The second underreamer run cut 4.3 m (14 ft) downward starting at 2926 m (9760 ft). A second interval, 3012 to 3017 m (9885 to 9900 ft), was also underreamed in a subsequent run.

A cement plug (designated plug No. 1) formulated of 500 sacks of class H cement was mixed by Dowell and spotted through open-ended drill pipe. It was designed to fill the borehole from 3149 m (10 331 ft), the top of the fish, to about 2911 m (9550 ft). However, when the drill string was tripped in to face off the cement, stringers were first met at 2968 m (9738 ft) instead of the planned 2911 m (9550 ft), a loss of about 55 m (180 ft). This loss could not

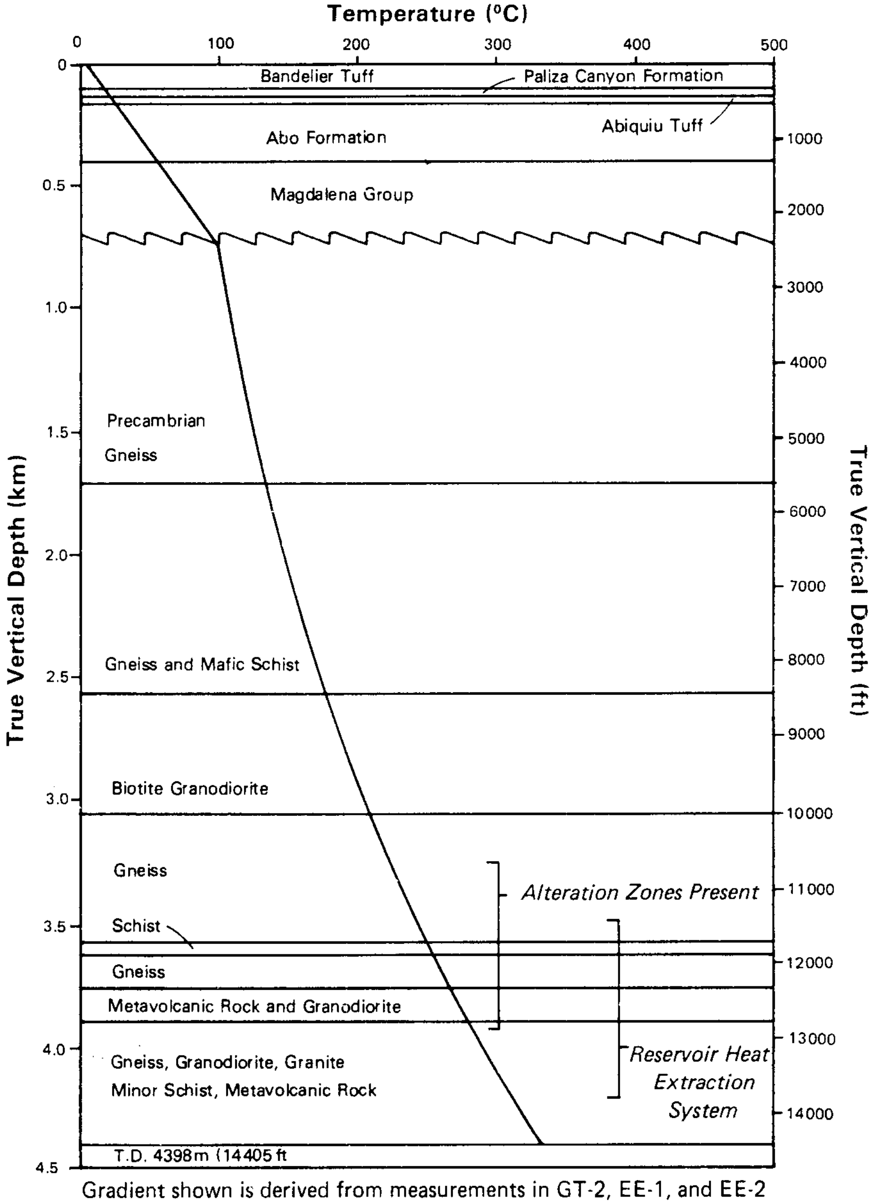

Fig. 6.
Generalized geological section and static conductive temperature profile at Fenton Hill.

be accounted for. The plug was faced off to 2978 m (9770 ft) and a second plug of 400 sacks of class H cement was placed with open-ended drill pipe. The top of the plug was tagged at about 2800 m (9188 ft) and dressed off with a mill-tooth bit to 2926 m (9600 ft) in preparation for starting sidetracking operations on day 215. However, after waiting 24 h on the cement plug to harden, drilling continued down to 3033 m (9950 ft), below both underreamed zones, in very soft (fast drilling) cement.

It was decided to pour a third plug that would be proceeded by a chemical wash intended to clean contaminants from the hole, and that would have less retarder to assure a sufficiently hard plug to sidetrack from. Cement-sample tests (by the Dowell Laboratory) showed a 4.13-MPa (6 000-psi) strength in 36 h at 175°C (350°F). Drill out of plug No. 3 indicated soft cement, that is 44.5×10^3N (10 000 lb_f) bit load drilled at 0.3 m/min (1 ft/min). A temperature survey, using the Los Alamos temperature tool, indicated that the cement had been emplaced at about 110°C (220°F), and not the 175°C (350°F) as planned, and the temperature for which the Dowell cement formulation was designed. An additional 24-h wait was initiated. Again the cement was found to be too soft, and it was drilled out to a depth of 9303 m (9950 ft). Another temperature survey was run and a projected placement temperature of 165°C (330°F) was derived and forwarded to Dowell. A special cooling program was suggested to lower the borehole temperature to 135°C (270°F), thought to be more nearly optimum for cement setting and hardening. Table I records the sequence and formulations of the cement plugs.

On January 1, 1981, day 225 since spud of the well, preparations for sidetracking were underway and the top of the fourth plug was tagged at 2913 m (9557 ft). However, drilling of this plug showed very soft cement. Rate of penetration was greater than 0.3 m/min (1 ft/min) with a 22.3×10^3N (5000 lb_f) load on the bit. The cuttings showed no chips so the cement had not set after 40 h of waiting.

At this point it was clear that a basic problem with the cement plugs existed, and it was decided to try a Halliburton cement formulation, (see Table I). The fourth Dowell plug was drilled out to a depth of 3081 m (10 109 ft) and a cool-down circulation was started. A special latch-plug subassembly and centralizers were run on the open-ended pipe to cool the hole and assure minimum cement-slurry disturbance on placement. On day 232, the fifth cement plug was placed.

It seemed clear at this point that special efforts would be required to obtain a cement plug hard enough from which to sidetrack. The technical problem is that to develop side forces (lateral loads) on the bit, a significant axial load on the bit is needed. It is possible to increase the side force by (1) using larger angle bent subs above the downhole motor, (2) use of a pressure-(flow-) activated kick sub (a Dyna Flex tool) to provide even larger angle, and (3) run in with a downhole PDM with a bent housing.

TABLE I

SUMMARY OF EE-3 SIDETRACKING CEMENT PLUGS

Date And Company	Cement Mix	Design Thickening Time and Temp	Temp Survey Measure-ment	Design Compressive Strength	Preflush	Type of Mixer	Depths Placement; Calc. Fill-up Tagged Top	Drilling Parameters	Coring Results	Core Compression Strength (psi)	Emplacement Method
12-18-80 Dowell (1)	500 sks Class H 5% D-99 Retarder 1% D-65 TIC[b] 35% D-66, Si flour (400 mesh)	8 h 370°F BHCT	338°F[a]	6000 psi 24 h	Plain water, 1 h	Hopper	10331 ft 9552 ft -196 ft	~1 ft/min, 5000 lbs 12-1/4 STC DSJ tooth bit; 48 h	---	---	Open-ended DP @ 10 331 ft
12-21-80 Dowell (2)	400 sks Class H 5% D-99 Retarder 1% D-65 TIC[b] 35% D-66, Si flour (400 mesh)	8 h 370°F BHCT	347°F[a]	6000 psi 24 h	None	Hopper	9744 ft 9218 ft +30 ft	~1 ft/min, 5,000 lbs 12 1/4" DSJ tooth bit; 72 h	---	---	Open-ended DP @ 9744 ft
12-25-80 Dowell (3)	300 sks Class H 3.5% D-99 Retarder 1% D-65 TIC[b] 35% D-30, Si sand (200 mesh)	3 h 370°F BHCT	270°F[a]	5650 psi 24 h	2000 gal CW-7 surfactant	Hopper	9950 ft 9410 ft. +30 ft.	~1 ft/min, 5,000 lbs 12-1/4 in. DSJ Tooth bit; 72 h	---	---	Open-ended DP @ 9550 ft
12-31-80 Dowell (4)	400 sks Class H 0.2% D-28 Retarder 1.25% TIC[b] 0% Silica	2 h 270°F BHCT	270°F	6000 psi 24 h	2000 gal CW-7 surfactant	Hopper	9925 ft 9527 ft +30 ft	~1 ft/min 5000 lbs 12-1/4 in. DSJ Toothed bit; 120 h	---	---	Open-ended DP @ 9925 ft
1-8-81 Halli- burton (5)	450 sks Class H 0.4% HR-12 Retarder 1% CFR-2 15% Si flour 15% Si sand (20-40 mesh)	2 h 270°F BHCT	250°F	2750 psi 12 h	2000 gal 7-1/2% acetic acid, bentonite gel, 75 sks Pozmix	Hopper	10 081 ft -55 ft	~1 ft/min, 9483 ft 9550-9565 ft 10 000 lbs, 12-1/4 in. DTJ Toothed bit;	cored 5000 lbs,	543 4-1/2days 96 hrs.	Open-ended DP @ 9951 ft Reciprocated pipe while displacing.

[a]Estimated.
[b]Turbulence enhancing compound.

TABLE I (cont.)

Date And Company	Cement Mix	Design Thickening Time and Temp	Temp Survey Measure-ment	Design Compressive Strength	Preflush	Type of Mixer	Depths Placement; Calc. Fill-up Tagged Top	Drilling Parameters	Coring Results	Core Compression Strength (psi)	Emplacement Method
1-15-81 Halli-burton (6)	350 sks Class H 0.75% CFR-2 40% Si flour No retarder	1.5 h 180°F BHCT	203°F	---	100 bbls Plain water	Hopper	9790 ft 9268 ft +160 ft	∿1 ft/min, 8000 lbs 48 h; 12-1/4 in.Smith DTJ tooth bit; 24 h 0.3 ft/min, 10 000 lbs. 96 h Dyna-Drill w/Q9J6 bit 1 ft/min, 2000 lbs. 192 h	cored 9600-9607 ft	4240	Open-ended 2-7/8 in. tbg. @ 9790 ft
1-29-81 Dowell (7)	230 sks Class H 0.2% D-28 Retarder 1% D-65 TIC[b] 40% Si flour	2 h 225°F BHCT	230°F	6000 psi 24 h	Plain water	Hopper	9880 ft 9480 ft +100 ft	0.3 ft/min, 10 000 lbs. 12-1/4 in.Hughes HH77, 36 h	---	---	Open-ended DP @ 9855 ft
2-3-81 Dowell (8)	300 sks Class J No retarder 20% Si flour 4% D-65 TIC[b]	2 h 225°F BHCT	--- 250°F		Plain water	Batch	0.5 ft/min 5000 lbs 9500 ft 9220 ft -45 ft	1 ft/min 5000 lbs 12-1/4 in. Smith DSJ tooth bit; 24 h	cored 9227-9242 ft core 9250-9267 ft 0.5 ft/min 10,000 lbs	2876 3 days 2505 7 days	12 jts 2-7/8 in. tbg. on bottom of DP @ 9482 ft
3-2-81 Halli-burton (9)	185 sks Class H 0.2% HC-12 0.75% CFR-2 40% Si flour (200 mesh)	2 h 275°F BHCT	250°F[a]	5275 psi 24 h	Plain water	Batch	set whipstock 9501 ft 9200 ft + 27 (30 ft 9471-9501 ft)	0.5 ft/min 10 000 lbs 12 1/4 in. 5DGH tooth bit	core 9270-9277 ft 12 ft/h	6450 7 days	Pumped through whipstock

[a] Estimated.
[b] Turbulence enhancing compound.

However, it is also necessary to keep the bit in contact with the borehole wall for some extended time, so time drilling or low penetration rate is required for effective sidetracking. The fifth plug was also found to be soft. It was conjectured that a core sample of the cement might indicate the nature of the problem with the plugs. A core was taken from 2911 to 2915 m (9550 to 9565 ft). The cement in the core was quite hard and appeared to be a fairly good quality plug. Drilling of the remainder of the plug indicated soft cement, that is a rate of penetration about 20 m/h (1 min/ft) with 22.5 x 10^3N (5000 lb_f) bit load, to a depth of 3078 m (10 100 ft).

In all, three more cement plugs were placed and several special placement procedures were followed; that is, the hole was especially well cooled to about 120°C (250°F). Water samples were analyzed, the hole preflushed, formulation changed to include 40% silica flour to replace the flour and sand mixture, and finally, the sixth through eighth cement plugs were cored and compressive strengths determined. Placement with a 7.1-cm (2-7/8-in.) centralized tubing string on bottom and no retarder was attempted on the sixth plug. This plug drilled relatively slowly (2-1/2 min/ft) with 44.5 x 10^2N (10 000 lb_f) bit load, therefore, it was decided to attempt to sidetrack the fish. Compressive-strength measurements on the core [75-mm (3-in.)-diam] gave 28 MPa (4000 psi), and a 2.5-cm (1-in.)-diam sample yielded 90 MPa (13 000 psi) compressive strengths.

The attitude of the bit was established at 26°N 72°E, which meant that the motor was oriented to drill out east of the high side of the hole. But repeated drilling from 4 m (14 ft) above the underreamed interval, starting at 2975 m (9760 ft), to 2 m (6 ft) below the bottom ledge, gave no positive sidetracking indications. Although some granite cuttings were noted, no sign of increase of load on the bit was indicated.

At this point, it was decided to set a whipstock above the fish at about 2800 m (9400 ft). The initial attempt was made with a 0.30-m (12-in.)-diam stock (that is the diameter at the lower solid end of the tapered, curved wedge). The whipstock hung up at about 2190-m (7200-ft) depth when run in the hole and subsequent reaming of the hole and trimming-off of some of the metal still did not allow this whipstock to be run in the hole. While waiting for a smaller diameter whipstock, another plug was placed and another sidetracking attempt was made.

A cement plug (H class, No. 7) was placed at 3011 m (9880 ft) and faced off to 2876 m (9500 ft). A gamma log was then run and an altered zone at 2856 to 2881 m (9370 to 9354 ft) identified. It was suggested that underreaming at that depth interval would provide a softer rock in which the PDM sidetrack drilling could cut a side-wall groove. Two underreamer runs were required to produce an enlarged section from 2833 to 2844 m (9293 to 9330 ft). A two-independent-arm caliper log was run and showed that a symmetric enlargement had been achieved. A special class J cement plug (No. 8) was placed and allowed to harden for 48 h. During this time the scheduled 64-arm caliper inspection was performed on the 34.0-cm (13-3/8-in.)-diam intermediate casing, and indicated that no new wear or damage had been sustained.

This plug was cored and showed a fairly high compressive strength, but also indicated that there were some mixing problems because distinct inhomogeneities were present in the cores. Two PDM (Dyna-Drill) runs were made with 22.2-cm (8-3/4-in.)-diam TCI bits and two with a special diamond sidetracking bits. The drilling rates were held to 0.3 m/h (1 ft/h). The second diamond-bit run started to show some signs of granite cuttings after 9 h of working up and down on the side wall of the underreamed zone. A three-cone TCI bit 22.2-cm (8-3/4-in.)-diam was then run in on a PDM and drilled with some signs of granite cuttings, but the cone tips were dropped and had to be fished with a magnet run. A second bit run with an 21.2-cm (8-3/8-in.) diamond bit and PDM drilled with load on bit and appeared to be sidetracked. Cuttings showed considerable granite, and the next run drilled 13.1 m (43 ft) and it was judged to have sidetracked. A rotary build assembly was run in the hole but would not take weight on the bit without drilling very rapidly, and therefore after only 1.2 m (4 ft) of drilling, another PDM was picked up and oriented with an EYE steering tool to continue sidetracking. However, after 5.8 m (19 ft), it was concluded that the sidewall grooving had not actually resulted in a sidetrack. The cement was drilled out to a depth of 2896 m (9500 ft) and a 27.3-cm (10-3/4-in.)-diam whipstock was prepared to be cemented in.

On day 283, after a temperature survey and appropriate cooling program, the second whipstock was run in with the wedge angle set to drill off at about 40°E of the high side of the hole, and successfully cemented. To assure a good set-up the cement was allowed to cure for four days while drill-pipe inspection, a thickness survey of the 13-3/8-in. casing and hardbanding of drill pipe was performed. The cement was tagged at 2781 m (9123 ft) and drilled with a 31.1-cm (12-1/4-in.)-diam mill tooth bit in hard cement to 2825 m (9270 ft). A core was taken and then the cement faced off just above the underreamed zone at 2835 m (9300 ft).

While drilling out the cement above the whipstock the bit encountered some junk (high-chromium steel), object(s) that were perhaps 1 m (3 ft) long. These object(s) required two runs with 21.9-cm (8-5/8-in.)-diam tapered and flat-ended mills and two magnet runs upon the approach to whipstock top at 2879 m (9444 ft). On day 299 the drill pipe twisted off in a collar connection, but the BHA was fished out promptly.

On day 302 a 31.1-cm (12-1/2-in.)-diam rotary assembly drilled down the length of the whipstock without problems. Two more magnet runs cleared the metal from the hole and on day 302, a 31.1-cm (12-1/4-in.)-diam TCI bit and a slick assembly drilled 2.4 m (8 ft) with clear indications of granite cuttings and therefore a 31.1-cm (12-1/4-in.)-diam inclination build assembly was run. On day 305 this building assembly drilled 296 m (97 ft) and verified by drilling rate, i.e., a rate of penetration 2.4 to 2.7 m/h (8 to 9 ft/h) with 200 x 10^3N (45 000 lb_f) bit weight, that granite was being drilled. Therefore, the sidetracking operations were complete. They had consumed 101 days.

The first valid survey below the whipstock was at 2900 m (9516 ft) and indicated 24°N73°E. (The steel in the whipstock and 10 m (30 ft) long tail-pipe anchor influenced the compass readings above that depth). This caused some concern since it seemed to imply that the drill-off from the whipstock may have been to the left, or west side of the hole, instead of the top and east (right) side as planned. It was decided to continue to drill to the next drill-pipe connection, 2913 m (9558 ft) and then pull the bit, replace the rig BOP stack, and order out a magnetometer proximity tool to determine range and distance from the sidetracked hole to the whipstock. The MINIRANGE tool (Jenson, Inc., Austin, TX) is designed to do such proximity evaluations. A second survey at 2901 m (9518 ft) had a confirming trajectory element of 24°N73°E.

The MINIRANGE tool indicated at 2893 m (9491 ft) that the direction from the old EE-3 hole (the whipstock tail pipe) to the newly drilled borehole was N90° ±5°E and the distance was 76 ±1.5 cm (30 ±6 in.). A multishot gyro survey was also run across the whipstock interval to confirm the change in direction of the new hole relative to the whipstock and the old EE-3 borehole. A directional drilling run with a PDM and the EYE steering tool was then made. The run consisted of 22 m (73 ft) and the steering tool indicated an inclination increase of 1° and a turn to the east of 7.5°. A build assembly with a six point near-bit reamer was then picked up and drilled ahead to 2962 m (9718 ft). A single-shot survey on the next rotary drilling build assembly yielded survey readings of 24-1/2°N 78°E at 2923 m (9753 ft) and 24-3/4°N 77°E at 2988 m (9805 ft).

The next few hundred feet of drilling were critical as the trajectory data indicated that the two holes could intersect. Attempts were therefore made to run another multishot gyro survey and a tandem magnetic multishot survey across the whipstock and into the newly drilled borehole. Instrument and operational problems plagued these surveys. Only one of the tandem multishot magnetic surveys was considered valid, and it generally confirmed the MINI-RANGE proximity tool data, so the decision was made to drill ahead with a build assembly. The conclusion was that the new hole would miss the old EE-3 borehole trajectory and no intersection would occur.

E. Continuation of Directional Drilling

The next 30 days were concentrated on orienting the EE-3 borehole properly above EE-2, establishing an inclination of 35°, and establishing a target trajectory vector for the EE-3 borehole that would be parallel to that of EE-2 and at the desired depth interval, i.e., 3230 to 3290 m (10 600 to 10 800 ft). Only about 300 m (1000 ft) of drilling remained to accomplish these objectives.

Using appropriate building assemblies, and six directional drilling runs with the high temperature MEI 19.7-cm (7-3/4-in.)-diam turbodrills, this section of the hole was completed. These 30 days included six days used for drill-pipe inspection, hard banding, and running of a 64-arm-caliper inspection log of the 34.0-cm (13-3/8-in.)-diam casing. On day 349, at a depth of 3289 m (10 791 ft), the hole diameter was reduced to 12.2-cm (8-3/4-in.)-diam by the drilling of a 6.0-m (20-ft) long section with a 25.1-cm (9-7/8-in.)-diam bit. The resulting trajectory elements for EE-3 in this reduced diameter transition section were determined to be very close to those planned.

F. EE-3 Trajectory at Hole-Diameter Reduction

At a TD of 3290 m (10 806 ft), TVD 3200 m (10 504 ft), a single-shot survey indicated 34-3/4°N 54°E, and that vector compared favorably with the borehole section below on the EE-2 trajectory that had the elements of a MD of 3526 m (11 568 ft), TVD 3458 m (11 344 ft), at 34-1/2°N 58°E.

These two points are plotted on Figs. 1 and 2 and indicate the relative positions and orientations of the two wells at these points. The region below these transition sections of the two wells is the reservoir portion of the HDR system, which is the objective of the EE-2/EE-3 drilling campaign.

G. Drilling the 22.2-cm (8-3/4-in.)-Diam Hole

The following 93 days were spent drilling the 22.2-cm (8/3-4-in.)-diam hole inclined at 35°. The drilling plan called for single-shot surveys every 20 m (60 ft), drilling with hold or build assemblies, and (by close monitoring of trajectory results) use of directional drilling to control the course of EE-3 within the required tolerances.

The drilling operations extended from day 349 to 443 when TD was achieved. This time interval was extended considerably due to several problems. The most troublesome was an extended fishing operation of 45 days duration. Problems were also encountered when H_2S formation was detected in the drilling-fluid reserve pits.

The first 8-3/4-in.-diam bit run was initiated at 3295 m (10 811 ft) and drilled steadily with a BHA designed to hold the inclination angle. After 24 m (309 ft) the slick-wire unit used to run the single-shot surveys failed and upon tripping out, while pulling wire, the drill string became jammed at a depth of 1918 m (6300 ft) in the 31.1-cm (12-1/4-in.)-diam hole. Fishing operations for the slick wire and unjamming the BHA took four days. The diagnosis was that a "keyseat" had formed in this zone, and the 17.1-cm (6-3/4-in.)-diam coupling on the drill string had worn a vertical groove into the borehole side wall sufficiently deep to jam the 17.1-cm (6-3/4-in.)-diam bodies of the drill collars or reamers in the 22.2-cm (8-3/4-in.)-diam BHA. When the BHA was on the rig floor, deep scrape marks were found only on the top of the topmost three-point reamer body, lending support to the theory of a keyseat. The keyseat zone was drilled and reamed out. A string reamer was also included on the next BHA to continue the reaming during the next bit run. A moderately strong rotary build assembly was used to drill to 3491 m (11 454 ft) and a single-shot survey showed 33-1/4°, N50°E.

On day 357 the drill string was laid down for inspection and the second string picked up. It had been decided that it was a significant time and cost saving to have a second string of drill pipe on hand so that drilling could proceed while inspection was accomplished. The drill pipe consisted of about 100 joints [approximately 1000 m (3000 ft)] of E-grade drill pipe on the bottom of the string, and some 250 joints of S-grade, high-strength pipe in the upper portion. This arrangement placed the more fatigue-resistant E-pipe in the higher temperature, lower portion of the string where high-fatigue loads would be expected. The high-strength pipe in the upper portion was placed where the larger pulling loads were applied. The string weight at this time was about 119 500 kg (250 000 lb_m), requiring a pulling force of 1.113 x 10^6N (250 000 lb_f). The S-grade pipe was needed since drag of 4.5 x 10^5N (100 000 lb_f) in excess of pipe weight was frequently experienced.

A build assembly was next run in the hole to correct the loss in inclination experienced by the previous bit run, but after only 43 m (141 ft) and two surveys, the BHA built 1-1/2° in 20 m (67 ft) and 2-1/2° in 42 m (137 ft). Drilling to a depth of 3631 m (11 914 ft), a survey indicated 36°N49°E. It was concluded that downhole-motor corrections would be required because the rotary drilling was continuing to drift too rapidly toward the left (north).

While a reaming assembly was being run to bottom, a piston rod on one of the drilling-fluid circulating pumps broke and suspicious-looking corrosion was inspected by a drilling-fluid field chemist (NL-Treating Chemicals). Hydrogen sulfide (H_2S) was detected in the break, scale on the drill pipe, and dissolved in the drilling fluid. This condition required that a bactericide be used to treat the solids in the bottom of the pits and that the level of dissolved H_2S in the fluid and the total sulfur* level in the fluid be reduced.

The first directional correction in the 22.2-cm (8-3/4-in.)-diam borehole was made on day 363 with a 7.6-m (25-ft) run with the smaller 13.7-cm (5-3/8-in.)-diam high-temperature MEI turbodrill. A low bit load of 2.2 x 10^4N (5000 lb_f) was used. The run was terminated when the bit apparently "locked up." Inspection of the bit indicated that the turbo-drill had spun off bottom and ground severe flats on the bit cones and terminated the run. The following reaming and drilling assembly with a hold BHA configuration got stuck twice as the lubricity of the drilling fluid had been lost due to the addition of the sulfur reducing chemicals to the reserve pits. The following drilling assembly also experienced very high torque and drag as reaming and drilling were attempted. Drilling to 3682 m (12 079 ft) was accomplished however. A test

*An amonium bisulfite system was being used for corrosion control.[8]

bit run was then made to evaluate the drilling-fluid conditions and a very high torque and drag force of $5.34 \times 10^5 N$ (120 000 lb_f) over string weight were present. The drilling-fluid specialists advised cleaning out the borehole, rig tanks, and reserve pits. The west reserve pit was emptied and recharged and the annulus was flushed. Drilling with the west reserve pit alone was initiated while the east pit was emptied and dredged out. The drill-pipe inspection of the original string indicated the presence of one cracked pin on the E-grade and eight cracked pins on the S-grade pipe.

Drilling continued to a depth of 4211 m (12 100 ft) with a survey result of 36°N 53°E. Two more directional runs with turbodrills brought the depth to 3833 m (12 576 ft) and had corrected the azimuth to 37°N 70°E. At this point the west reserve pit was channeling and rig-pump-suction temperature had reached 65°C (130°F) and some cuttings were being sucked into the rig circulating pumps. A four-day halt in drilling operations was necessary while the east reserve pit was cleaned out with a dragline, front loader, and vacuum trucks.

An earthen dam was placed across the middle of the east pit. These two separate pits thus formed would be used as the cuttings-settling and fluid-cooling system, and the western pit would be abandoned. The pits were now renamed numbers 1, 2, and 3, from west to east and pit No. 1 was abandoned.

On day 383, the chemical analysis of pit No. 2 showed less than 5 ppm H_2S and a pH of 10.5 so drilling operations were resumed with a packed, inclination holding assembly. Drilling progressed smoothly with some high-torque and tight-hole conditions encountered. These troublesome conditions decreased as the concentration of the lubricity additive increased and the hole cooled down. At a depth of 3930 m (12 895 ft), the trajectory survey gave 36-3/4°N 66°E, and a second directional correction was required. Wireline, cable head, and turbodrill problems plagued this operation. The special high-temperature EYE steering tool equipment was sent from California. While awaiting these instruments, a rotary hold assembly was run. Drilling continued for three days and reached a depth of 4074 m (13 365 ft). A survey at 4061-m (13 324-ft) depth gave 36°N 73°E and indicated that the trajectory was drifting slowly toward the north and away from the desired N80°E orientation.

The accumulated 100-h rotating time on the drill string dictated that it should be laid down and inspected. The new string was picked up, and a 64-arm caliper survey inspection of the 34-cm (13-3/8 in.)-diam casing showed that no additional wear had occurred. The new wireline was found to be spliced and had allowed water entry so the scheduled directional run was delayed and a packed, holding BHA was picked up.

It was necessary to start reaming at a depth of 4048 m (13 280 ft). At a bit depth of 4063 m (13 330 ft), the drill string twisted off with the bit 10 m (35 ft) above bottom. No excessive torque or drag had been experienced, and the string had just been inspected.

This twist-off had occurred at 1860 m (6102 ft) and was a result of a failure in a pin thread. The clearing of the fish required 45 days, and was finally completed on day 439.

Successful removal of the drill pipe and BHA required a progression of steps. The initial free-point survey indicated that the drill string was essentially free down to the BHA. Problems were encountered with all free-point and back-off shot tools due to the high temperatures. The approach to the fishing job was to back off and remove the upper part of the string, lay it down, and replace it with S-pipe. It was necessary to perforate the HWDP above the BHA in order to establish the circulation needed to cool the hole so that back-off shots would work.

After eight days, two joints of HWDP had been backed off, the E-pipe all removed, and a fishing assembly with heavy fishing jars was run into the hole to grapple the fish. The recovered E-pipe was only slightly bent, which was an encouraging sign because it indicated that the BHA might not have fallen very hard and was probably not jammed in the bottom of the hole. However, the subsequent jarring did not move the fish. This was very likely due to the cushioning effect of the remaining 25 joints of HWDP above the BHA. It was then necessary to remove as much as possible of the HWDP.

Back-off attempts failed, so a pipe-severing service (Jet Research Center, Houston, Texas) was called in to cut the HWDP. A premature firing occurred at 3989 m (13 088 ft), but did not cut the HWDP; apparently the detonator was affected by the temperature. The second jet severing tool fired properly at 3948 m (12 943 ft) down in the fifth joint of HWDP.

While tripping the fish and string out of the hole, the string jammed in the keyseat at 1920 m (6300 ft) but was cleared quickly, easily, and cleanly. The keyseat was reamed again with a 22.2-cm (8-3/4-in.)-diam reaming assembly run above a flat-ended mill with two three-point reamers back-to-back. The milling assembly encountered tight-hole conditions, so a reaming assembly was run in. However, it became evident that the problem was drilling-fluid related, not a tight-hole condition, because the reaming apparently did not improve the drag situation. The milling BHA was circulated and washed to bottom on day 412 and the milling run ground off about 2 m (5 ft) of the HWDP, indicating that the tool joint (coupling) had been reached in the milling run. This fact was confirmed by the wear on the mill. The overshot grapples would not hold the fish so another milling run was conducted, but the grapples still would not hold. During a third milling run, the drill string twisted off at about 1585 m (5200 ft) and required a grapple overshot to remove the milling assembly on day 419.

Chemistry check of the No. 2 reserve pit indicated that 40 ppm of H_2S was present (10 ppm H_2S is considered a critical level). A very large increase had occurred overnight. The rig pits were filled with clean water and the hole flushed clean. Grade- E drill pipe was used to avoid exposing the high-strength grade-S pipe to the high H_2S level.

Drill-string change out and inspection were performed on day 420 of the operations. Meanwhile, the drilling-fluid field engineers and chemists were attempting to clean up and control the H_2S levels in the No. 2 and 3 pits. Also the keyseat at 1980 to 2040 m (6500 to 6700 ft) was reamed again since the last milling run had indicated some tightness as the assembly was pulled up through this interval. The rig tanks were used for circulating fluid because the reserve pits were still too high in H_2S level and the bacteria were very active in them. The plan was to innoculate the bottom slime of pit No. 2 with a strong biocide using a jet nozzle and hose arrangement and to abandon pit No. 3. This procedure occupied three days.

Two final milling runs were conducted on days 423 and 424. The milling had cleaned the coupling and exposed the 11.4-cm (4-1/2-in.)-o.d. section of the HWDP. On day 427, after problems of setting overshot grapples were solved, the fish was pulled* from the hole. Next a series of junk baskets and magnet runs was made to clear the large number of chunks of steel found on bottom. Ten magnet and junk-basket runs were required, interspersed with milling, tooth-bit, and carbide-insert-bit stirring runs to clean out the

*The hydraulic drilling jars in the fish were operating effectively, in tandem with fishing jars, after 35 days exposure to the 260°C (500°F) static bore-hole temperature.

bottom of the hole. These clean-out operations consumed nine days before a final mill-tooth bit run assured that clean bottom of the hole was clean.

Drilling of the 22.2-cm (8-3/4-in.)-diam hole resumed on August 1, 1981. A packed, hold assembly was run in the hole and drilled to a depth of 4113 m (13 494 ft) when the drill string twisted off at a depth of 2951 m (9683 ft). The failure was again found to be a thread in a pin. Fishing this time occupied only one day because the BHA was on bottom drilling when the twist-off occurred. The grapple latched onto the box on the first try and the fishing jars loosened the fish with little effort.

Drilling with a packed-hole assembly continued, and the drill string was inspected joint by joint on the rig floor as it was run in the hole. Two pins with cracks in the threads were found, rejected, and laid down.

Drilling proceeded with only one further problem. The drilling jars washed out and leaked so a trip was required to replace the jars. Four days of steady drilling continued until the bit torqued up and stopped drilling at 4084 m (13 933 ft). It was decided this was to be the last bit run and the TD of the EE-3 well. The last bit had drilled 134 m (439 ft) in 34.5 h of drilling at a rate of penetration of 4.8 m (12.7 ft/h). The TD was about 150 m (500 ft) short of the planned 4.39 km (14 400 ft) depth.

A final single-shot survey was made at 4225 m (13 861 ft) and gave a trajectory element of 36-1/2°N 73°E. The borehole had started to drift back to the east slightly and the horizontal TD position of EE-3 projected to the location of the TD of EE-2, below, was estimated to be 60 m (180 ft) north.

H. Borehole Cleaning, Casing Running, and Cementing

The final 18 days of the EE-3 drilling operations were spent running the 24.4-cm (9-5/8-in.)-o.d. production casing, first-stage cementing, tensioning the casing, and cementing the second stage. And finally, drilling out cement, running cement bond and neutron-gamma logs over the cased interval, and performing a flush and cleaning operation for the open-hole reservoir section of the hole.

The initial cleaning consisted of running to TD of the well with a double set of scrapers above a 22.2-cm (8-3/4-in.)-diam bit. This BHA was then short tripped up to the 31.1-cm (12-1/4-in.)-diam transition point at 3292 m (10 800 ft) and then returned to TD. The reservoir portion of the hole was circulated and then its contained fluid displaced with a 2% detergent solution intended to soak in place until the casing was run and the final cleaning (that was planned following the casing, cementing, and tensioning procedures) was performed.

A temperature survey, which included two dwells* to obtain temperature recovery data, was performed by the Los Alamos instrumentation group. The temperature at 3353 m (11 000 ft) was recorded as 197.81°C with a recovery rate of 0.6°C/h. A Schlumberger borehole-geometry gauge (a two-independent-arm-caliper tool) was also run. These measurements were used to relay projected temperature levels to the cementing engineers at Dowell for sample testing and retarder additions, and to provide data for annulus volume calculations for cement-quantity determinations. A cement plug was set below the projected production casing shoe depth. This required the placement of two plugs, because the first plug flowed down into the 22.2-cm (8-3/4-in.) hole below. A compensated neutron-gamma log was then run (by Schlumberger) to provide for a before-and-after evaluation of possible water pockets left during the cementing.

The high strength (P-110 grade, 47 lb_m/ft) casing was inspected both for body defects and for imperfections in threads and couplings. A total of 15 (5.3%) joints was rejected. This premium-grade-connection casing (Valercor, VAM type) was selected to avoid the potential failure modes of connection separations and collapse during the tensioning and heat-extraction-production phases, respectively, in the life of the casing.

The second cement plug was set and a preliminary flush (pH=12.2) was performed to clean the hole of "black gunk" that had been adhering as a heavy coating to all logging tools and the BHA that were removed from downhole. A triple tally of the casing was performed as it was placed on the pipe racks.

The second cement plug was faced off to a depth of 3170 m (10 400 ft). The casing jacks with sub-base and supports, were set on the cellar floor and adjusted. The 263 joints of casing were run into the hole without any difficulties. Two additional joints of casing were rejected (6% total rejection) when the torque-turn monitoring system indicated that they had failed to make up properly. The casing joint below the topmost joint had stress gauges installed so that the loads below the wellhead slips could be monitored during hang-off, cementing, flushing, and tensioning operations. This joint and the

*A hold at one vertical station to record the temperature time recovery at that depth.

landing joint were selected to be a lower carbon steel and of heavier weight (L-80 grade at 53.5 lb_m/ft) so that they would accommodate the gripping action of the wellhead slips and could be field welded during subsequent wellhead attachment and sealing.

The first-stage cementing was then performed. The formulation, Table II, was designed to have a preflush of water and of pozzolan (fly-ash) material, followed by a special H-class, high-temperature cement mixture designed to yield a high-strength and low-permeability cement. This first stage was designed to be pumped, with 25% excess provided, to fill the annulus for 1000 m (3000 ft) from the bottom. At the top of the first stage at a depth of 2219 m (7281 ft), a stage collar cementing valve (DV tool) had been installed in

TABLE II

CEMENT FORMULATIONS AND VOLUMES FOR THE EE-3 9-5/8 IN. PRODUCTION CASING

Stage 1	
Preflush	20 bbls H_2O followed by 350 sacks pozzolan (fly-ash), with 1.2% D-28 retarder.
Slurry	950 sacks class-H cement with 144 bbls H_2O, 40% silica flour and 40% silica sand (100 mesh) with 0.75% D-65 turbulence enhancer, 2% D-20 bentonite, 0.2% L-10 retarder catalyst, and 1.2% D-28 retarder.
Displacement	Displaced with 701 bbls H_2O (760 bbls design).
Stage 2	
Preflush	20 bbls H_2O
Slurry	1200 sacks class-H cement with 1 ft^3/sack perlite, 191 bbls H_2O, 2% D-28 retarder, 20% silica flour, 20% 100 mesh silica sand, 0.75% D-65 turbulence enhancer, 2% bentonite and 0.2% D-46 antifoaming agent.
Displacement	Displaced with 517 bbls H_2O.

the casing string. This valve was opened after the cement was placed, and the excess cement in the annulus above the valve flushed out and displaced to the surface.

On day 453, nine days into the casing running and cementing operations, the 72-h period of waiting on the first-stage cement ended. A temperature survey was run by the Los Alamos instrumentation personnel. The temperature at the DV tool at a 2219 m (7282 ft) depth was 138°C with a rebound rate of 0.1°C/h. Testing and mixing of the second stage cement (Table II) was performed by Dowell. The Dowell fracturing truck (used to pressurize the hydraulic jacks), high-pressure plumbing, and all procedures were double checked, and a hydrostatic test run to 103 MPa (15 000 psi). The wellhead slips were adjusted and the jacks were reciprocated to work the tension down to about 1964 m (6444 ft) as determined by the observed stretching of the casing.

On day 455, the second-stage cementing job was completed. The volume of the slurry (Table II) had been carefully calculated from the caliper log to just fill the annulus to a depth of 1000 m (3000 ft), which was 1305 m (4282 ft) above the top of the first stage. The design was to provide about 150 m (500 ft) of open formation below the shoe of the 34.0-m (13-3/8-in.)-diam intermediate casing string. This should prevent any high pressures from building up in the upper annulus between the two casing strings. Figure 7 records the final well configuration for EE-3 with the casing and cementing details and depths recorded.

The second-stage cement mixing operations met with some difficulty when the first batch of lightening agent (perlite) would not mix into the slurry. This batch, and the second, were pumped with the perlite addition by running in on the fly into the hose line. The closing (bumper) plug was dropped and the stage cementing valve (DV tool) closed after a precise displacement with water.

The pretension of the upper part of the casing was then accomplished. Three loading cycles were sufficient to work the tension down and the final cycle to 3.94×10^6N (885 000 lb_f) stretched the casing 2.8 m (8.1 ft). The slips were set and the top joint was cut off 1.5 m (5 ft) above the wellhead.

The plugs, DV tool, 93 m (275 ft) of cement, and the cementing shoe were drilled out with two trips with 21.6-cm (8-1/2-in.) mill-tooth bit. Junk baskets, run in the BHA above the bit, were retrieved with pieces of very hard

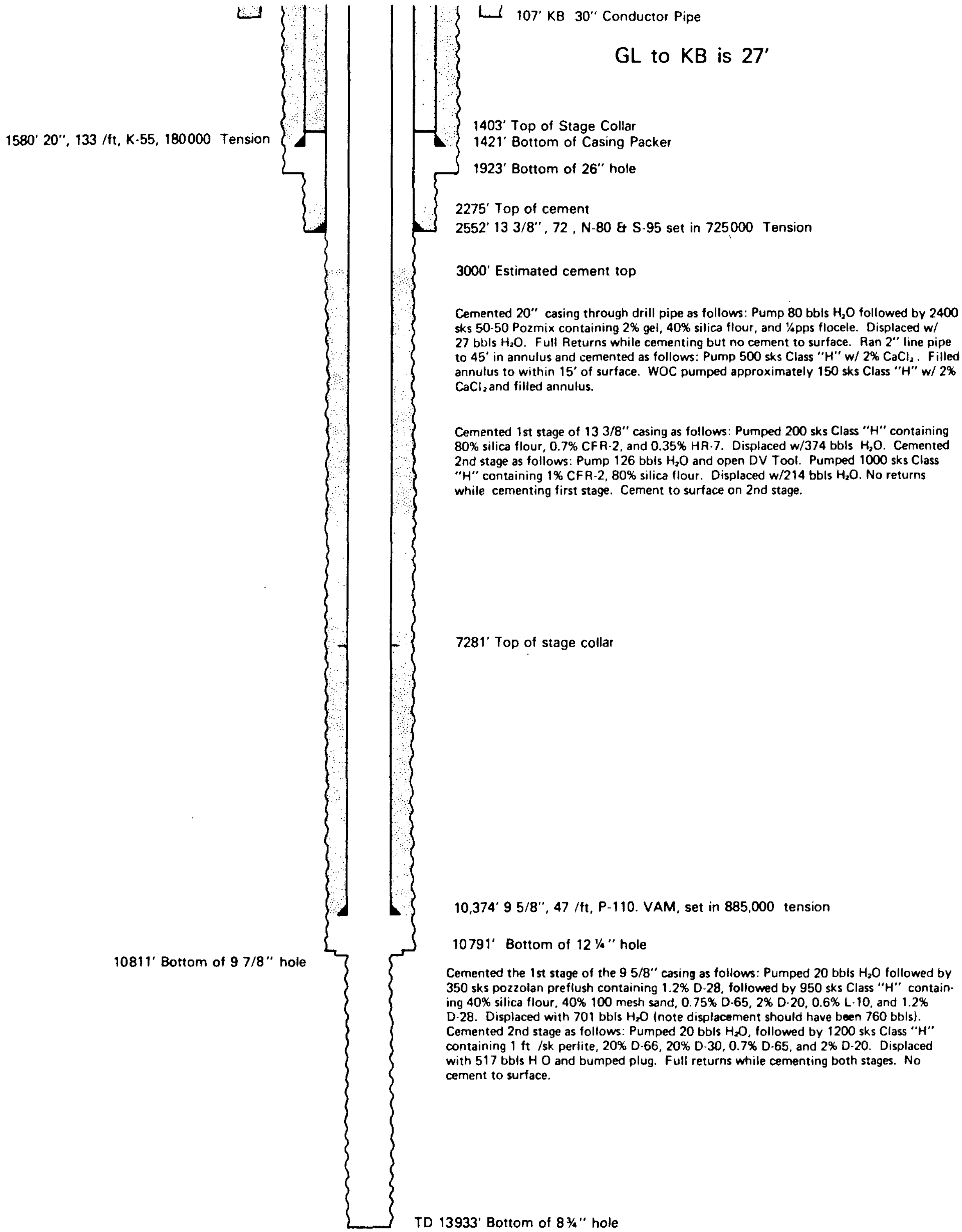

Fig. 7.
Wellbore diagram for EE-3.

cement and the cuttings were in the form of hard chips verifying that a good initial set of the first-stage cement had occurred.

Following high-viscosity gel sweeps to clean out the cement cuttings thoroughly, the cement plugs below the casing shoe were drilled out from 3169 m to 3426 m (10 397 to 11 241 ft). Soft cement, with considerable black gunk (the thermally degraded lubricating agent), was encountered so the hole was circulated again with a gel sweep. The cement-bond log and postcementing run of the compensated-neutron and gamma-density log were accomplished on day 459. The final cleaning consisted of washing and reaming down to TD with a 21.6-cm (8-1/2-in.)-diam bit, two circulating volumes of high-alkaline (pH=12.5) flushing solution and a final displacement with clean water.

At 6:00 a.m. August 25, 1981, the drill pipe had been laid down, the flow line cut off, the conductor pipe removed from the wellhead, and Brinkerhoff Signal Drill Rig 56 was released.

III. CONTROLLED-TRAJECTORY DRILLING

The planned controlled-trajectory drilling of EE-3 and the formation of the reservoir section above EE-2 required a high-precision application of directional drilling technology. The wellbore path of the injection well EE-2 had been established,[2,11] with the completion of drilling of that well on May 12, 1981. The directional drilling operations and equipment used in well EE-2 had established[4-7] the basic approach and had dictated the directional drilling procedures required to direct and control the trajectory of EE-3.

Various equipment items had been tested and two definite temperature limits were established. At temperatures less than about 200°C (400°F), PDMs could be used. This corresponds to depths less than about 3 km (10 000 ft) at Fenton Hill. These downhole drilling motors are constant-volume-displacement devices, and therefore bit rpm is controlled directly by the flow rate of the drilling fluid. The tools are widely available on a rental basis. Downhole bit reaction torques are reproducible and familar to directional drilling engineers. This has the advantage of providing a relatively reliable preset of the reaction twist of the drill string. This often allows the directional control to be performed with single-shot surveys run between motor runs. Therefore PDM directional drilling may not necessarily require the use of the much more expensive continuous-readout directional-steering tool instrumentation.

At temperatures above 200°C (400°F) two sizes of all-metal, high-temperature rated turbodrills were available. The PDMs have elastomer stators and radial bearings and therefore are inherently temperature limited by the performance of these temperature sensitive components. The 19.7-cm (7-3/4-in.)-diam turbodrills were used in the directional drilling of EE-2.[9] A total of 21 directional runs was made in the 31.1-cm (12-1/4-in.)-diam portion of that well.[10] Two smaller 13.6-cm (5-3/8-in.)-diam turbodrills were tested at the TD of EE-2 and in the TerraTek Drilling Research Laboratory (Salt Lake City, Utah). These tools were designed to perform directional drilling in the 22.2-cm (8-3/4-in.)-diam borehole. Both sizes of MEI turbodrills were designed with specific operating characteristics to match the torque, bit weight, and power capacity required to drill granite with TCI three-cone rock bits of the sizes and types to be used in the Fenton Hill directional drilling operations.

A commercial firm (Scientific Drilling Controls, Irvine, California) had developed and successfully tested a high-temperature version of their EYE steering tool in the bottom portion of the EE-2 well. These tests had been performed during the trials of the smaller diameter MEI turbodrills.

The directional drilling strategy for EE-3 used downhole motor runs guided by a steering tool, that were alternated with rotary drilling assemblies intended to hold or build the inclination angle of the borehole trajectory. The downhole-motor runs were primarily used to change azimuth of the wellbore. The rotary assemblies were used to hold or build inclination, but primarily to drill hole, and secondarily to ream out an undergauge section or to ease a tight zone caused perhaps by a crooked hole created by previous directional runs.

A. Downhole Motor Directional Control

The 64 directional downhole motor runs are summarized in Table III. The typical BHAs used with these motor runs are listed on Table IV.

The planned KOP was 2010 m (6600 ft) and the wellbore was drilled initially with very tight-packed hole assemblies to the depth of 1964 m (6444 ft). The inclination built up steadily to 10° and drifted in the west-northwest direction. The drift experienced was very similar to that realized for the previous wells GT-2[11] and EE-1.[12-14] This drift apparently reflects the natural drilling characteristics of the granite in this depth interval. The first changes in azimuth were planned to be accomplished at low-inclination

TABLE III

SUMMARY OF DIRECTIONAL DRILLING RUNS AND RESULTS FOR WELL EE-3

Directional Drill Motor Run No.	Drill Motor[a]	Steering Tool Service[b]	Bent Sub Angle	Measured Depth[c] m (ft)	Borehole Trajectory	Distance Drilled m (ft)	Remarks
1	BPDM	SS	2°	1981 (6520)	9 1/2°N,53°W	23 (76)	Problems with motor
2	BPDM	SS	2°	2027 (6649)	14 3/4°N,54°W	39 (129)	Angle building excessively
3	BPDM	EYE	2°	2075 (6809)	14 3/4°N,37°W	30 (99)	Replace bit
4	DDPDM	EYE	2°	2083 (6868)	14 1/2°N,20°W	17.9 (59)	Plugged bit on connection (no float)
5	DDPDM	EYE	2°	2168 (7114)	13°N,23°E	64.3 (211)	Motor quit, bit very worn, 2.5 cm (1 in.) undergauge
6	BPDM	EYE	2°	2216 (7269)	10 1/2°N,43°E	27.4 (90)	Motor stalled
7	BPDM	EYE	2°	2216 (7269)	---	0 (0)	Bit pinched and motor bent, hit ledge going into hole
8	NPDM	EYE	2°	2236 (7337)	10 1/2°N,43°E	20.7 (68)	Bit worn
9	NPDM	EYE	2°	2264 (7427)	8 3/4°N,62 1/2°E	27.4 (90)	Bit worn
10	NPDM	EYE	2°	2281 (7482)	7°N,47°E	16.8 (55)	Bit worn, bit 13 mm (1/2 in.) undergauge
11	DDT7D	EYE	1 1/2°	2395 (7856)	---	0.3 (1)	Steering tool failed, test run of turbine
12	DDPDM	EYE	1 1/2°	2402 (7883)	15 3/4°N,51°E	8.2 (27)	Dull bit
13	DDPDM	EYE	1 1/2°	2409 (7905)	15°N,47°E	6.7 (22)	EYE quit, motor and bit worn out
14	DDPDM	EYE	1 1/2°	2420 (7940)	16°N,51°E	10.7 (35)	Motor quit
15	NPDM	EYE	1 1/2°	2454 (8052)	16 1/4°N,59°E	34.1 (112)	Bit locked up
16	NPDM	EYE	1 1/2°	2457 (8062)	---	3.0 (10)	Could not orient due to torque
17	NPDM	EYE	1 1/2°	2486 (8159)	---	28.0 (92)	Bit cones loose
18	NPDM	EYE	1 1/2°	2490 (8170)	---	3.4 (11)	Motor quit
19	NPDM	EYE	1 1/2°	2519 (8265)	16 1/4°N,87°E	28.9 (95)	Bit locked up
20	DDT7S	---	---	2562 (8407)	17 1/2°N,84°E	0 (0)	Tachometer not operative, motor not rotating, straight hole tool with stabilizer, test run of turbine
21	DDT7S	---	---	2562 (8407)	17 1/2°N,84°E	0 (0)	Could not get to bottom, reamed 27 m (90in.), straight hole tool with stabilizer, test run of turbine
22	NPDM	EYE	1 1/2°	3011 (9879)	25 1/2°N,66°E	8.8 (29)	Bit dull
23	NPDM	EYE	1 1/2°	3011 (9879)	25 1/2°N,66°E	0 (0)	Motor wouldn't rotate, reached temperature limit of PDMs

TABLE III (cont.)

Directional Drill Motor Run No.	Drill Motor[a]	Steering Tool Service[b]	Bent Sub Angle	Measured Depth[c] m (ft)	Borehole Trajectory	Distance Drilled m (ft)	Remarks
24	DDT7D	EYE	1 1/2°	3053 (10,017)	24°N,72°E	0 (0)	Washout in drill string
25	DDT7D	EYE	1 1/2°	3053 (10,017)	24°N,72°E	0 (0)	Turbine would not rotate
26	MEIT7	EYE	1 1/2°	3083 (10,116)	27°N,70°E	30.4 (99)	Bit undergauge, build angle attempt
27	MEIT7	EYE	1 1/2°	3085 (10,123)	27°N,70°E	2.1 (7)	Turbodrill quit, build angle attempt
28	MEIT7	EYE	1 1/2°	3094 (10,150)	27°N,67°E	8.2 (27)	Bit locked up, build angle attempt
29	MEIT7	EYE	1 1/2°	3110 (10,204)	27 3/4°N,68°E	16.5 (54)	Bit undergauge, build angle attempt
30	MEIT7	EYE	2°	3150 (10,334)	27 1/4°N,51°E	9.4 (31)	Motor quit, build angle attempt
31	MEIT7	EYE	2°	3163 (10,378)	24 3/4°N,66°E	13.4 (44)	Dropping angle, steering tool seated 170° from key
32	MEIT7	EYE	2°	3175 (10,417)	24 3/4°N,66°E	11.9 (39)	EYE failed
33	MEIT7	EYE	2°	3189 (10,463)	24 3/4°N,66°E	14.0 (46)	Motor quit, radial bearing failed, build angle attempt
34	MEIT7	EYE	1 1/2°	3197 (10,489)	24 3/4°N,66°E	7.9 (26)	Bit locked up, undergauge, 0.9 cm (3/8-in.)
35	MEIT7	EYE	1 1/2°	3209 (10,528)	26 1/4°N,66°E	0 (0)	Motor would not rotate, tight hole
					Motor Runs For Sidetracking Attempts		
36/37	DDPDM	EYE	f	2981 (9780)	(26°N,72°E)[d]	16.8 (55)	Time drilling, first two sidetracking attempts
38	DDPDM	SS	(2°)[e]	2836 (9304)	(22 1/2°N,72°E)[d]	1.2 (4)	Plugged BHA
39	DDPDM	SS	f	2840 (9319)	(22 1/2°N,72°E)[d]	4.6 (15)	Time drilled, motor stalled
40	DDPDM	SS	f	2842 (9323)	(22 1/2°N,72°E)[d]	1.2 (4)	Time drilling, diamond bit
41	DDPDM	SS	f	2842 (9323)	(22 1/2°N,72°E)[d]	0 (0)	Time drilling, sidetracking attempt
42	DDPDM	SS	f	2843 (9329)	(22 1/2°N,72°E)[d]	1.2 (4)	Time drilling, sidetracking attempt, diamond bit

TABLE III (cont.)

Directional Drill Motor Run No.	Drill Motor[a]	Steering Tool Service[b]	Bent Sub Angle	Measured Depth[c] m (ft)	Borehole Trajectory	Distance Drilled m (ft)	Remarks
43	DDPDM	SS	f	2846 (9339)	(22 1/2°N,74°E)[d]	3.0 (10)	Time drilling, sidetracking attempt, lost cone tips
44	DDPDM	SS	f	2860 (9382)	(23 1/2°N,72°E)[d]	13.0 (43)	Time drilling, sidetracking attempt, bit dull
45	DDPDM	EYE	(2°)[e]	2870 (9416)	(21 3/4°N,71°E)[d]	8.5 (28)	Time drilling, sidetracking attempt
46	DDPDM	EYE	f	2864 (9396)	(21 3/4°N,71°E)[d]	26.2 (86)	Time drilling, last sidetracking attempt
				Directional Control 31.3 cm (12 1/4-in.) Hole [Whipstock Set at 2878 m (9444 ft)]			
47	DDPDM	EYE	1 1/2°	2913 (9559)	24°N,73°E	0.3 (1)	Motor failed and plugged bit
48	DDPDM	EYE	1 1/2°	2936 (9631)	24°N,75°E	21.9 (72)	Turn hole to east, avoid old hole
49	DDPDM	EYE	2°	2978 (9771)	24 1/2°N,78°E	12.9 (42)	Turn hole to east, avoid old hole
50/51	MEIT7	EYE	1 1/2°	3117 (10,226)	31 1/2°N,74°E	0 (0)	Float failed, plugged two turbodrills[g]
52	MEIT7	EYE	1 1/2°	3123 (10,245)	31 1/2°N,72°E	5.6 (19)	Eye wireline failed[h]
53	MEIT7	EYE	1 1/2°	3155 (10,352)	28°N,67°E	29.6 (97)	Pulled due to drop in inclination
54	MEIT7	EYE	2°	3189 (10,462)	30 3/4°N,57°E	18.3 (60)	Light weight on assembly, good run
55	MEIT7	EYE	1 1/2°	3245 (10,654)	32°N,56°E	24.7 (81)	Good run
56	MEIT7	EYE	2°	3289 (10,791)	34°N,55°E	17.4 (57)	Both floats failed
				Directional Control 22.2 cm (8 3/4 in.) Hole			
57	MEIT5	EYE	1 1/2°	3643 (11,951)	35 1/4°N,53°E	7.6 (25)	Dull bit
58	MEIT5	EYE	1 1/2°	3695 (12,123)	36°N,53°E	7.3 (23)	Dull bit
59	MEIT5	EYE	1 1/2°	3714 (12,186)	35 1/2°N,59°E	19.2 (63)	Pulled for survey
60	MEIT5	EYE	1 1/2°	3752 (12,310)	35°N,72°E	36.3 (119)	Bit locked up, good run
61	MELT5	EYE	1 1/2°	3950 (12,961)	36°N,73°E	20.1 (66)	Radial bearing cage twisted

TABLE III (cont.)

Directional Drill Motor Run No.	Drill Motor[a]	Steering Tool Service[b]	Bent Sub Angle	Measured Depth[c] m (ft)	Borehole Trajectory	Distance Drilled m (ft)	Remarks
				Directional Control 31.3 cm (12 1/4-in.) Hole [Whipstock Set at 2878 m (9444 ft)]			
62	MEIT5	EYE	1 1/2°	3950 (12,961	36°N,73°E	0 (0)	Bit pinched
63	MEIT5	EYE	1 1/2°	3950 (12,961)	36°N,73°E	0 (0)	Eye tool failed
64	MEIT5	EYE	1 1/2°	3950 (13,365)	36°N,73°E	0 (0)	Eye tool failed, motor plugged while waiting

[a]Key for downhole motion types:
BPDM = Baker Service Tools.
DDPDM = Dyna-Drill (Smith International).
NPDM = Navi-Drill (Christensen Oil Tools).
DDT7D = Dyna-Drill, 7 in. directional turbine.
DDT7S = Dyna-Drill, 7 in. straight-hole turbine.
MEIT7 = Maurer Exploring Inc., 7 in. turbine.
MEIT5 = Maurer Exploring Inc., 5 3/8 in. turbine.

[b]SS = Single-shot orientation; EYE = Scientific drilling contents steering tool.

[c]Measured depth at end of run.

[d]BHA oriented to drill out ~40° east of high side of borehole.

[e]Run with Dynrlex Unit.

[f]Bent Housing Dyna Drill.

[g]Started running tandem float valves.

[h]Used high temperature float seals for remainder of runs.

TABLE IV

TYPICAL DOWNHOLE MOTOR BHA USED IN EE-3

Bit or Hole Diameter cm (in.)	Motor Type	Typical Assembly	Remarks
31.1 (12-1/4)	PDM	Motor, float sub, bent sub, orienting sub, 8-in. Monel drill collar, 10 8-in. drill collars, jars, 17 joints HWDP.	Used at depths less than 3 km (10 000 ft) limited to maximum temperature of 200°C (400°F).
	MEIT7	Turbodrill, float sub, bent sub, orienting sub, 8-in. Monel drill collar, 13 8-in. drill collars, jars, 17 joints HWDP.	High temperature, 200°C (400°F). Run No. 26-32 Table III.
	MEIT7	Turbodrill, float sub; bent sub, orienting sub, 2 6-3/4-in. Monel drill collars, 3 6-3/4-in. drill collars, 9 joints HWDP.	Used in very crooked hole below 3.2 km (10 300 ft), Run No. 33-35. Table III, prior to twist-off.
31.1 (12-1/4)	DDPDM	Motor, bent sub, float sub, orienting sub, 2 8-in. Monel collars, 5 8-in. collars, jars, 12 joints HWDP.	Used during sidetracking attempts 2840 m to 2980 m (9800 to 9300 ft).
31.1 (12-1/4)	DDPDM (Bent Housing)	Motor,[a] Dyna Flex or bent sub, orienting sub, 2 6-3/4-in. Monel drill collars, 4 6-3/4-in. drill collars, 7 8-in. drill collars, jars, 12 joints HWDP.	Used during sidetracking attempts 2840 m to 2980 m (9800 to 9300 ft).
22.2 (8-3/4)	MEIT5	Turbodrill, float sub, bent and orienting sub, 2 6-3/4-in. Monel collars, 5 6-3/4-in. drill collars jars, 27 joints HWDP	Used for eight directional corrections below hole diameter reduction point at 3.29 km (10 800 ft) Run No. 57 - 64 Table III.

[a] Eight runs with 1-3/4° bent housing DDPDM.

angle because it is far easier operationally to correct azimuthal angle at low inclination. The objective was to redirect the wellbore from the northwest to the northeast quadrant while holding the inclination angle low.

As indicated in Table III, the first two directional downhole PDM runs were attempted without a steering tool. The first motor run (a Baker Service Tools PDM, denoted BPDM) torqued up and stalled repeatedly and was pulled. Magnetic single-shot surveys were obtained as each joint of drill pipe 10 m

(30 ft) was drilled down. The second BPDM performed better, but there was difficulty experienced with excessive build rate in inclination angle and a SDL developed. (See section on DRILLING PROBLEMS below). The succeeding eight directional-control motor runs achieved close to the desired azimuth, N47°E, at a depth of 2281 m (7482 ft). However, the inclination dropped to 7°. Directional runs and rotary drilling continued relatively routinely. At a depth of 3184 m (9715 ft) the trajectory elements were 27°N 68°E when a rotary build assembly was noted to be building too fast so the load on the bit was reduced and this resulted in a very sharp inclination angle drop, see Fig. 3, at the 2988- to 3013-m (9805- to 9836-ft)-depth interval. The inclination dropped 3° to 23°.

At 3051 m (10 017 ft) the downhole motor use was switched to the 19.7-cm (7-3/4-in.)-diam MEI turbodrills (Run No. 26 in Table III) and a building run was made. This resulted in a very sharp increase in inclination angle to 27°. A subsequent motor run at 3150 m (10 334 ft) was misoriented, due to wear of the steering tool muleshoe and orienting sub, by 170° and the intended building run actually dropped inclination again. Tight-hole conditions were subsequently experienced during efforts to build angle and ream out the severe crooked hole section resulting from the oscillation in inclination in the borehole above. A twist-off of the drill pipe occurred at a bit depth of 3175 m (10 417 ft) and as the directional drilling attempts continued, tight-hole conditions dictated the replacement of the 20.3-cm (8-in.) drill collars with 17.1-cm (6-3/4-in.) drill collars. A serious twist-off occurred again at 3209 m (10 528 ft) while reaming the tight hole. Directional drilling was suspended for 145 days for fishing and sidetracking (see DRILLING PROBLEMS section below).

Eleven PDM runs were conducted during the sidetracking attempts, as shown on Table III (Runs 36 through 46). These were motor runs oriented with both single-shot surveys and steering tools, generally intended to drill out of the high side of the hole and to the east. Since time drilling was desired, and temperatures were below 200°C (400°F), PDMs were used. Although two of the time drilling sequences produced some evidence of granite (biotite) in the cuttings, all sidetracking attempts were unsuccessful.

Immediately following the rotary drill-off from the whipstock [(placed at 2879 m (9444 ft)] three PDM directional drilling runs were made, two successfully, to direct the hole toward the east and build angle. These were crucial directional runs because the original EE-3 wellbore trajectory had an increasing inclination angle in this region (Fig. 4) and was trending eastwardly beyond the whipstock location. Rotary build assemblies were then used to build the inclination by 7° and hold the azimuth in the N70°E to N80°E range until a depth of 3116 m (10 226 ft) was reached. At this depth five MEI turbodrill directional runs out of seven attempts (Run Nos. 50—56 in Table III) succeeded in achieving a trajectory orientation of 34°N 55°E at a depth of 3344 m (10 971 ft). This was close enough to an alignment parallel to EE-2 so that the hole diameter was reduced by drilling 7 m (20 ft) with a 22.5-cm (9-7/8-in.)-diam bit. A single-shot survey point at 3294 m (10 806 ft), in the middle of this transition, read 34-3/4°N 54°E. The corresponding point 366 m (1200 ft) TVD below on EE-2 had trajectory elements of 3675 m (12 056 ft) TVD and survey elements of 34°N 55°E.

The plan for the 22.2-cm (8-3/4-in.)-diam borehole, the reservoir section of the drilling program, was to straight-hole rotary drill with a very tightly packed BHA. Runs with these drilling assemblies would be interrupted only if the azimuth or inclination varied from parallelism with EE-2 by the tolerances stated in the drilling plan above. It was projected that the rotary hold BHA drilling would drift or walk in a manner similar to the rotary drilling response of the rock in well EE-2 at depths of 370 m (1200 ft) below.

In practice two sequences of directional turbodrill runs were successfully accomplished, as shown by the segments A and B on Fig. 2. In all, eight directional corrections were attempted as necessary when the hold assemblies drifted or walked north (to the left) too far. A third attempt, the last four runs in Table III, at 3951 m (12 961 ft) only accomplished a 20 m (66 ft) run but altered the azimuthal course of the trajectory by nearly 7°. From this point on the rotary drilling was allowed to continue to drift and swung off to the north, instead of drifting east as EE-2 had done. This deviation was only about 24 m (80 ft) beyond the tolerance limit at the TD of 4247 m (13 933 ft) for EE-3.

B. Downhole-Motor Performance

Table V records the performamce of the downhole motor assemblies used. These BHA performance results include the collars, bent-sub, motor, bit, float valve, and steering tool. The behavior of such assemblies is dependent on the proper function of all components of the directional system. The major reasons for a directional run abort (in order of frequency) were when the

TABLE V

DOWNHOLE MOTOR DIRECTIONAL DRILLING ASSEMBLY[a] PERFORMANCE IN EE-3
(Excluding Sidetracking Operations)

Motor Type	Total No. of Runs Attempted	No. of Runs that Drilled	Average[b] Distance per Run[c] m	(ft)	Average[b] ROP per Run m/h	(ft/h)	Average[b] Duration of Run, h	Diam of Motor cm (in.)
MEIT 7[d]	17	14	13.2	(43.3)	3.9	(12.7)	3.4	19.7(7-3/4)
MEIT 5[d]	8	5	18.1	(59.3)	8.6	(28.2)	2.1	13.7(5-3/8)
NPDM[e]	10	9	19.0	(62.2)	4.5	(14.8)	4.0	20.3(8)
DDPDM[e]	8[f]	8	18.2	(59.6)	3.3	(10.8)	5.5	19.7(7-3/4)
BPDM[e]	5	4	30.0	(98.5)	2.1	(7.0)	14.0	17.1(6-3/4)

[a] The assembly performance includes bit, motor, float valve, bent and orienting subs, and steering tool.

[b] Based upon successful runs; i.e., those that drilled.

[c] Note that most directional runs were set up with a 20 m (60 ft) length, 2 joints, of drill pipe initially in the derrick.

[d] High temperature turbodrills.

[e] NPDM = Navidrill (Christensen Tool Co.); DDPDM = Dyna-Drill (Smith International Inc.); BPDM = Baker Motor (Baker Service Tools, Inc.).

[f] Excluding those used for sidetracking.

orienting or steering tool failed, bit dulled, float valve leaked (plugging motor), or the motor failed. Another mode of failure experienced was those occasions when the motor would not start when oriented properly. In the directional drilling of EE-3 this was usually due to too tight a hole, caused by a too-sharp directional change (SDL) or by insufficient reaming. This problem was often solved by reaming to bottom with the motor, or starting the motor drilling in a series of short runs (a bit length each) with successive small azimuth-rotation increments until the proper orientation was established and the motor would then rotate.

It is noted in Table V that the three PDM tools performed about equally well. The BPDM ran longer and thus achieved an average distance drilled of three joints of drill pipe. This motor has the lowest rpm and highest torque characteristics of the three PDMs and therefore, provides a more extended bit life. This lower rpm performance also resulted in the observed lower penetration rates for the BPDM.

Two types of commercial all metal turbine motors were tested during the EE-3 drilling program. Two 17.8-cm (7-in.)-diam Dyna-Drill (Smith International) directional motor tests, denoted as DDT7D in Table III, Run Nos. 11, 24, and 25 were conducted. These high-temperature Dyna-Drill directional turbodrills were also candidates for use for directional corrections in the high-temperature section of EE-3. Also, two straight-hole (DDT7S, in Table II, Run Nos. 20 and 21) high-temperature Dyna-Drill turbodrills were run with limited success due to hole conditions. The Dyna-Drill turbine runs were supported by the Sandia National Laboratory Geothermal Drilling and Completions R&D Program. It appears that these motors have excellent high-temperature capabilities and will find application in geothermal well directional drilling operations where their performance characteristics (e.g., torque capability) are applicable.

The two sizes of high-temperature MEI turbodrills generally operated very satisfactorily. The 19.7-cm (7-3/4-in.)-diam tools were used in the 31.1-cm (12-1/4-in.)-diam hole. In all, there were 17 total attempts and 14 drilling runs were achieved. The three turbodrill failures were due to two cases of float valve failures that resulted in plugged bearings and one incident where the motor was stalled due to tight-hole conditions (Run No. 35, Table III). Termination of directional runs with these motors was most often due to the EYE steering tool malfunctions; second in frequency was failed float valves, and the third ranked cause was from worn (usually locked-up bearings or undergauge) bit.

The eight directional drilling attempts with the 13.7-cm (5-3/8-in.)-diam MEI turbodrills were all conducted in the 22.2-cm (8-3/4-in.)-diam reservoir section of the borehole. These tools had been tested in EE-2 and in the laboratory with the EE-3 directional operations as a goal. All three aborted runs, the last three attempts (Run Nos. 62-64 in Table III), were terminated due to EYE steering tool failures. Had these last three runs been successful, it is likely that the deepest part of the EE-3 trajectory could have been directed within the lateral tolerances originally planned. These two smaller diameter turbodrills performed very well. The operations were stable and reliable once the directional drilling engineer learned that a high load on bit, 89 000 to 1 113 000 N (20 000 to 25 000 lb_f) was required. Problems with excessive bit wear, bit lift-off, and turbine-speed run-away conditions experienced in three short runs (Nos. 57-59 in Table III) resulted from this problem of insufficient bit weight. The result was extremely rapid flat wear on the bit cones, Fig. 8, when the turbodrill spun off bottom. It was as though the bit was run up against a high-speed grinding wheel. The anticipated problems with inability to control speed and keep a consistent bit load were not experienced. Performance was monitored by the attainment of a steady rate of penetration (ROP), and generally indicated rotational speeds of 350 to 450 rpm as derived from rotary and turbodrill drilling tests in granite blocks and the turbodrill performance curves developed in laboratory tests.[16]

C. Rotary Drilling

Most of the drilling of both EE-2 and EE-3 was performed using rotary drilling methods with TCI button bits. Blade-type stabilizers were initially used in the BHAs to keep the hole straight. Because these wore rapidly in the granitic formations, they were replaced by six-point and three-point roller stabilizers with replaceable rotating rollers. Smooth-faced rollers were used when wall contact was required for stabilization, and knobby roller-cutters with TCI were used for reaming.6,7 A near-bit reamer was included in all rotary BHAs. The near-bit reamer is required to prevent too rapid decrease in hole diameter as the bit gauge wears. Standard "fulcrum" type lifting or build assemblies were used for increasing the inclination of the borehole during rotary drilling. However, the borehole trajectory usually walked or drifted to the left or right at unpredictable rates when using rotary drilling for building angle with these assemblies. The walk tendencies of EE-3 differed from those experienced in EE-2.

Several different types of rotary BHAs can be used to build, drop, or hold inclination angle. For EE-3, only build and hold assemblies were used, and Figure 9 shows simplified schematic sketches of typical BHAs and their functions. Table VI records some of the principle assemblies used for the rotary drilling of EE-3.

Drilling of the 66.0-cm (26-in.)-diam hole was started with an unstabilized BHA (entry 1, in Table VI); however, the assembly tended to build angle rapidly. A hold assembly (No. 2 in Table VI), was substituted. That BHA used nonrotating stabilizers. This hold assembly worked well and inclination buildup was held to less than 2°. The nonrotating stabilizer used was a four-bladed, full-gauge rubber sleeve tool that rotates freely on a mandril. The drill string rotates, but the sleeve does not. This kept the stabilizer

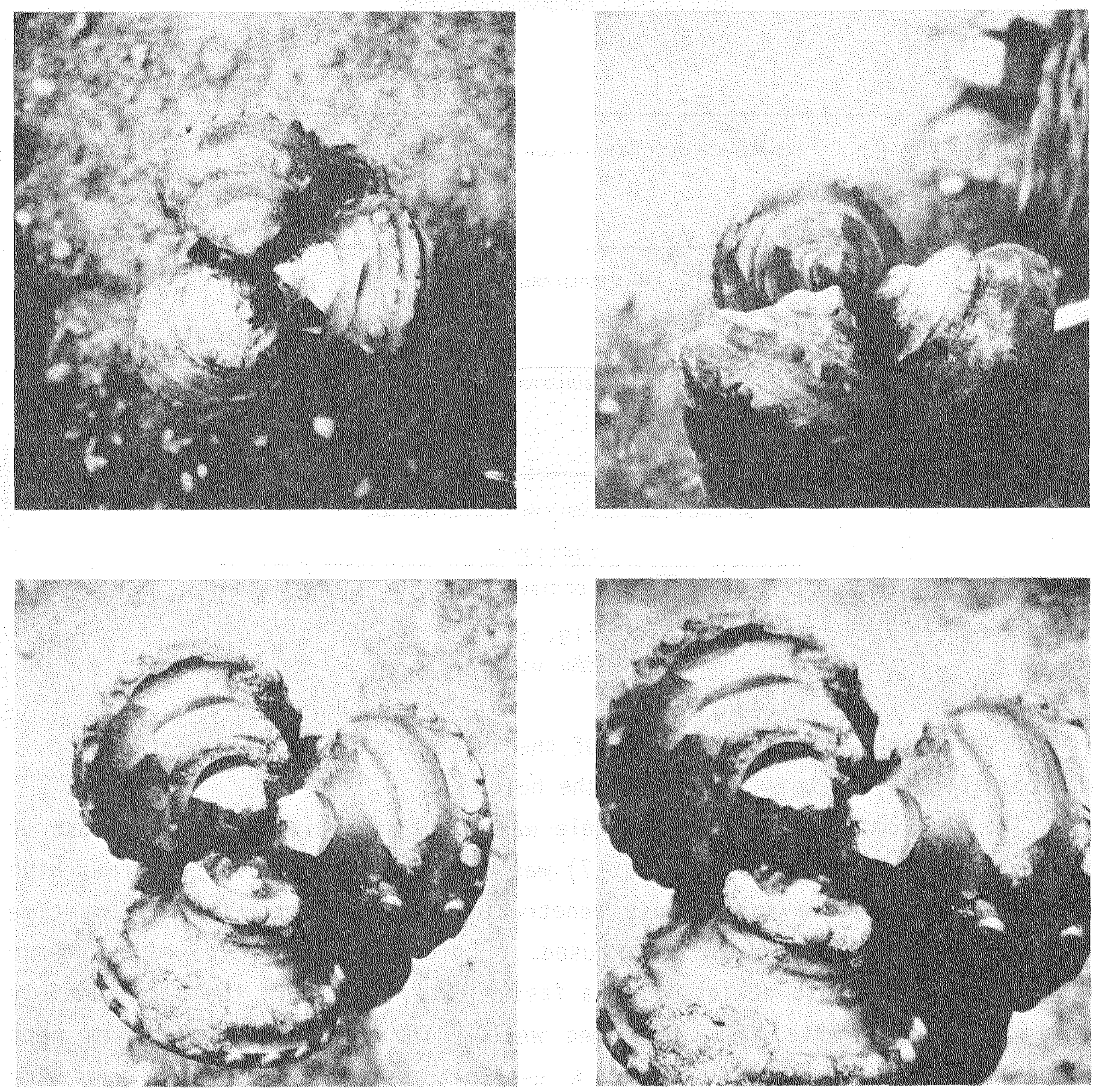

Fig. 8.
Views of 8-3/4-in. bits with severe wear flats due to turbodrill overspeed at too-light bit loading.

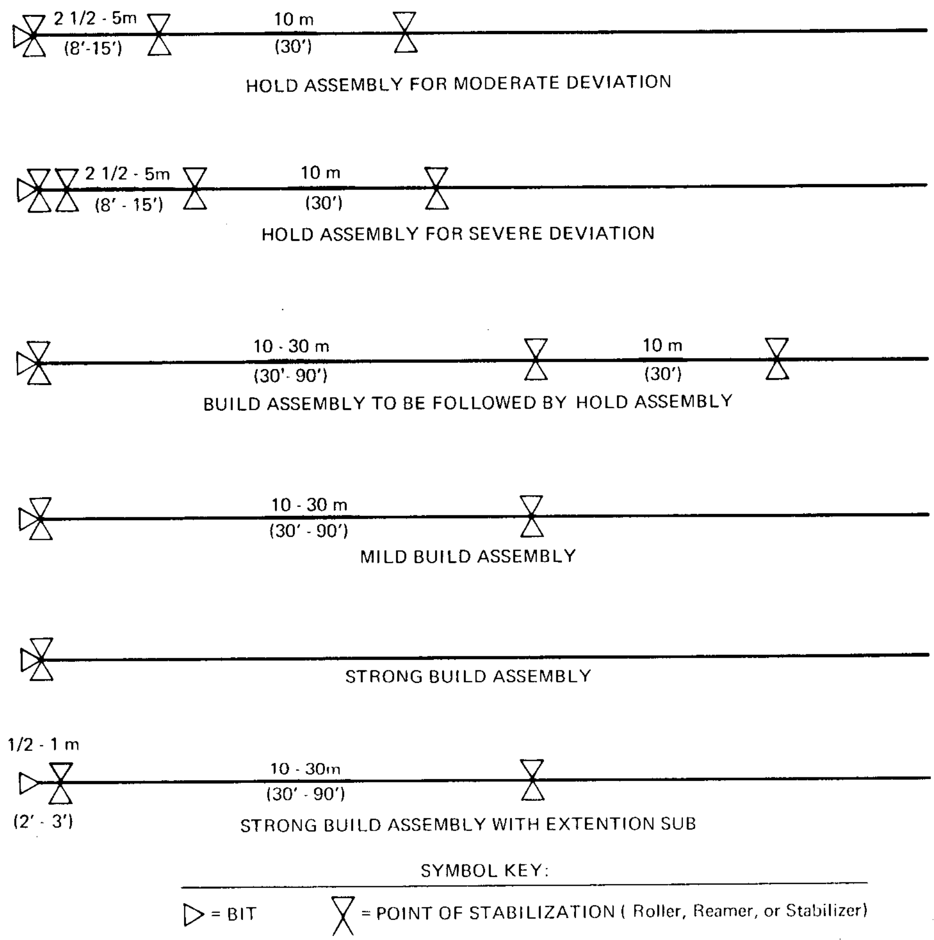

Fig. 9.
Typical BHAs used in EE-3.

from digging into the borehole wall of the soft volcanic and sedimentary formations (Fig. 6) in this section of the hole.

The 44.5-cm (17-1/2-in.)-diam hole was fully stabilized. Because most of this section of the hole (see Fig. 7) was drilled without fluid returns, high bit loads were needed to increase penetration rate to minimize drilling time required and the quantity of water used. Unfortunately, increased bit force may tend to cause hole deviation at a faster rate. However, the hold assembly used (No. 3 in Table VI), performed well. The hole inclination was kept within the desired limits (<1°). A near-bit three-point reamer was used instead of a nonrotating stabilizer to keep the hole in-gauge while drilling the harder limestones and granite in the lower section of the 17 1/2-in.-diam hole.

The blade-type stabilizers used in the 66.0-cm (26-in.)-diam and 44.5-cm (17-1/2-in.) holes, were replaced by roller reamers or roller stabilizers in

TABLE VI

TYPICAL BHA USED TO ROTARY DRILL EE-3

Number	Hole Size	Typical BHA	Type	Remarks
1	26 in.	Bit X-O, 9-in. DC, Shock Sub, Monel DC, 5 9-in. DC's, 14 8-in. DC's, Jars, X-O, 5 6-3/4-in. DC's.	Drilling	A soft-formation assembly that can be used where deviation is not a problem.
2	26 in.	Bit X-O, X-O, Stabilizer,[a] Shock Sub, Stabilizer,[b] Monel DC, Stabilizer,[b] 6 9 in. DC's, 14 8 in. DC's, Jars, X-O, 6 6-3/4 in. DC's.	Hold	A soft-formation assemmbly used to hold angle.
3	17-1/2 in.	Bit, X-O, Three-Point Reamer, X-O, Shock Sub, Stabilizer,[a] Monel DC, Stabilizer,[a] 6 9 in. DC's, 14 8 in. DC's, Jars, X-O, 6 6-3/4 in. DC's.	Hold	Used to hold angle. Three-point reamer is used for gauge protection.
4	12-1/4 in.	Bit, Six-Point Reamer, Three-Point Reamer, X-O, Shock Sub, Three-Point Reamer, Monel DC, Three-Point Reamer, 14 8 in. DC's, X-O, 10 6-3/4 in. DC's, 20 Joints HWDP.	Hold	Used to keep the upper portion of the 12-1/4 in. hole straight.
5	12-1/4 in.	Bit, Three-Point Reamer, Short Drill Collar, Three-Point Reamer, Monel DC, Three-Point	Ream	Assembly was used to ream after
6	12-1/4 in.	Bit, Three-Point Reamer, X-O, Shock Sub X-O, 6-3/4 in. Monel, 1 6-3/4 in. DC, X-O Three-Point Reamer, 1 8 in. DC, Three Point Reamer, 11 8 in. DC's, Jars, X-O, 17 Joints HWDP.	Build	Used to build angle. Built too fast.
7	12-1/4 in.	Bit, Six-Point Reamer, Float Sub, Shock Sub, Monel, DC, 9 8 in. DC's, X-O, Jars, X-O, 12 Joints HWDP.	Build	Six-point reamer was used to keep the assembly from building too fast. Also used for reaming turbodrill runs since the hole drag is high. Three-point reamer had been substituted at times to build angle faster.
8	12-1/4 in.	Bit, Float Sub, DCs, Three-Point Reamer, Shock Sub, 2 8 in. Monel, 7 8 in. DC's, X-O, Jars, X-O, 15 Joints, HWDP.	Build	The float sub between the bit and three-point reamer is used to increase the side force of the bit and thus build angle faster.
9	8-3/4 in.	Bit, Six-Point Reamer, X-O, Short Drill Collar, Three-Point Reamer, Monel, Three-Point Reamer, Monel, X-O, 11 6-3/4 in. DC's, Jars, X-O, 15 Joints HWDP.	Hold	A holding assembly used to drill the 8-3/4-in. hole.

Number	Hole Size	Typical BHA	Type	Remarks
10	8-3/4 in.	Bit, Three-Point Reamer, Float Sub, X-O, Monel, Three-Point Reamer, X-O, 5 6-3/4 in. DC's, Jars, X-O, 37 Joints HWDP.	Hold	Mild holding assembly. The three-point reamer was substituted for the six-point reamer to reduce hole drag. A 30 ft monel was used between the first two stabilizers to obtain surveys closer to bottom, even though it makes the assembly more flexible.
11	8-3/4 in.	Bit, Three-Point Reamer, Short Drill Collar, Three-Point Reamer, Monel, Three-Point Reamer, X-O, 5 6-3/4 in. DC's, Jars, X-O, 37 Joints HWDP.	Hold	Three-point reamer used to reduce hole drag.

Nominal Length of BHA Components

Drill Collar (DC)	30.5 ft	Short Drill Collar	10.0 ft
Monel Drill Collar	30.0 ft	Shock Sub	10.0 ft
Hevi-Wate Drill Pipe	30.5 ft	Float Sub	2.0 ft
Six-Point Reamer	8.0 ft	Cross Over (X-O)	1.5 ft
Three-Point Reamer	5.0 ft	Drilling Jars	32.0 ft

[a]Blade stabilizer.
[b]Nonrotating blade (rubber) stabilizer.

the 31.1-cm (12-1/4-in.)-diam hole. This was necessary because the rubber stabilizers wear much too quickly on granite and will not take high temperatures. Rotating metal-blade stabilizers also wear excessively and cause too much hole drag and high torque at the rotary table. So roller reamers were used for stabilization. The rotating cutters act as bearings between the BHA and borehole wall. They do not have enough wall contact to be used as stabilizers in softer formations; but in granite, the reamers perform satisfactorily.

The 31.0-cm (12-1/4-in.) hole was drilled from 783 m (2567 ft) to 1964 m (6444 ft) using a hold assembly. This was intended to be the straight section of the hole in the crystalline rock. The principal assembly used to drill this section of the hole is entered as No. 4 in Table VI. The upper section of this hole drilled relatively straight, but the lower section was slightly inclined due to formation effects. Bit load had to be reduced to keep from building angle too quickly even though a tightly packed hold assembly was run. The inclination had built to 10° at 6444 ft. This depth was the KOP for EE-3 — the point at which the directional drilling started.

At the KOP, downhole motors were run to change the azimuthal direction of the well from northwest to northeast. A section of hole drilled with high-speed downhole motors has to be reamed because the TCI bits used on downhole motors wear and lose gauge very rapidly. A reaming assembly similar to No. 5 in Table VI is run to bring the hole back into gauge. Note that this assembly is also a stiff packed or hold assembly. A hold assembly is the stiffest assembly that will be run in the hole; therefore, any other assembly can follow it. If the hole had been reamed out with a less-rigid assembly, a subsequent more-rigid hold assembly would have to be reamed to bottom should it become necessary to run one in the following rotary drilling sequence.

At 2280 m (7482 ft) the azimuth direction of EE-3 had been changed to parallel the trajectory of EE-2, a build assembly (No. 6 in Table VI) was run to build angle at 1° - 1-1/2° per 30 m (100 ft); however, this assembly built angle too fast. It is interesting to note that the same assembly built angle at a maximum of 1-1/2°/100 ft in EE-2, but in EE-3, the assembly built angle at 2-1/2°/100 ft. The 17.1-cm (6-3/4-in.) drill collars in this build assembly were run in place of the 20.3-cm (8-in.) drill collars so that the assembly would build angle faster. This is because the 17.1-cm (6-3/4-in.) collars are more flexible than the 20.3-cm (8-in.) collars and bend more sharply at comparable bit loads.

Three reamers were run in this assembly even though one or two reamers can be used to build angle effectively. The purpose of the second and third reamer is to make the assembly stiffer without affecting the ability to build angle. Also, the third reamer reduced the amount of reaming required by the subsequent hold assembly to be run to bottom.

At the depth of 2390 m (7840 ft) more direction change was required and downhole motors were again used to change the direction from N46°E to N88°E at 2562 m (8407 ft). In order to be 370 m (1200 ft) vertically above EE-2 at an inclination of 35° and at a measured depth of approximately 3170 m (10 400 ft), a hold assembly was consequently run. If angle building had continued, EE-3 would have been more than 1200 ft above EE-2 when 35° inclination had been reached. The hold assembly worked well as the inclination did not change. The previous building assembly was then run and, again, built angle too fast. Therefore, another assembly was run with the distance between the reamers shortened from 30 m (90 ft) to 20 m (60 ft). This assembly still built rapidly, so the load on bit was reduced to control the rate of build (see Fig. 3). The rate of build slowed, but the inclination began to drop at the end of the bit run, probably due to formation effects. The next bit run continued to drop angle so a turbodrill had to be used at a depth of 3011 m (9879 ft) to redirect the hole back upwards. Fishing and sidetracking operations were necessary shortly thereafter.

After EE-3 was successfully sidetracked, alternating build assemblies and motor runs were made. Entry 7 in Table VI shows one of the typical assemblies run. A six-point reamer was used to keep from building angle too fast. Also, it is noted that only one reamer was run. At this point, it was assumed that a hold assembly would no longer be necessary in the 31.1-cm (12-1/4-in.) hole. The previous assembly would not build angle fast enough below 3109 m (10 200 ft); therefore, a three-point reamer with an extension sub between bit and bottom reamer was substituted for the six-point reamer. This assembly should have built angle faster, but it built angle at a maximum of 1-1/2°/100 ft. It is interesting to note that this performance corresponds to that of EE-2 at similar depths. This sequence of rotary runs shows the unpredictable then "predictable" role that the formation effects can play in directional drilling.

Through a sequence of turbodrill runs and use of building assemblies similar to the one mentioned above, an inclination of 34-1/2° and azimuth of N54°E were obtained, almost exactly as planned.

The 22.2-cm (8-3/4-in.) hole was to be drilled as a straight hole inclined at 34-1/2°. Therefore, hold assemblies were run throughout the length of the 22.2-cm (8-3/4-in.) hole, with one exception. That exception was one run with a build assembly. Turbodrill azimuth corrections were attempted three times in the 22.2-cm (8-3/4-in.) hole, with two successful azimuth changes achieved.

Initially the packed-hole hold assemblies used were those depicted as No. 9 in Table VI. The assembly did hold, but inclination tended to drop angle slightly, at a rate less than 1/2°/100 ft. A building assembly was then successfully used to rebuild angle. The assembly built 3-1/2° in 200 ft. Assembly 10 in Table VI has 10 m (30 ft) between the first and second reamers, which makes it a build assembly at high bit loads; however, the assembly was run primarily to ream motor runs, and therefore did not drill very far. The purpose of this assembly was to obtain single shot surveys closer to bottom. In this assembly, the Monel drill collar was placed just above the bottom three-point near-bit reamer, which locates the survey approximately 7 m (20 ft) deeper than for a more conventional hold assembly.

The remainder of the hole was drilled with assembly No. 11 in Table VI. In this assembly the six-point reamer was replaced with a three-point reamer to reduce hole drag. The assembly drilled at a relatively constant inclination angle. The angle fluctuated between 35° and 36°, which is about as expected. The hold assemblies used for the 22.2-cm (8-3/4-m) EE-2 also fluctuated slightly, with about a 1° amplitude, so both wells drilled similarly in that respect.

For the most part, the rotary assemblies run in EE-3 did what they were designed to do, but the rate at which they changed inclination angle was neither predictable nor easy to control.

IV. DRILLING FLUIDS PROGRAM

A. Volcanics and Sediments

The drilling-fluid-system additives used for EE-3 were direct extensions of those previously used for wells GT-2, EE-1, and EE-2 at Fenton Hill.[2,8,12-15] The upper volcanic and sedimentary rocks were drilled using a bentonite-based drilling fluid. Due to the large, 66.0-cm (26-in.) and 44.5-cm (17-1/2-in.) hole sizes, an inverted-rheology fluid was selected to assure adequate hole cleaning. This property was provided by adding a polymeric flocculant. Solids control de-silters were used to remove cuttings and prevent mud weight build up that could fracture the formations. No temperature problems with additives were experienced, or expected, since the maximum temperature of 100°C (200°F) is experienced at the contact with the granite at about 800 m (2400 ft).

Lost circulation was again the major problem associated with the upper volcanic and sedimentary formations. Slight losses of returns that occurred in fractured portions of the volcanic tuff [surface to 137 m (450 ft)] were quickly and easily plugged with conventional fibrous bridging agents such as cottonseed hulls, cedar fiber, and aspen fiber. In sharp contrast, very severe loss occurred in the cavernous-limestone portion of the Pennsylvanian, Sandia, and Madera Formations. This loss of returns resulted in a drastic loss of hydrostatic head (fluid level 274-518 m (900-1700 ft)] leaving no fluid in contact with portions of the unstable Abo Formation. As a direct result of this situation were problems of stuck pipe, repetitive reaming of sections of the borehole, and a poor casing cement job for the intermediate casing string [34.0-cm (13-3/8-in.)] for EE-2.

Loss of circulation in the Abo Formation was minimal. In earlier wells drilled at Fenton Hill (GT-2 and EE-1) almost no loss occurred, but the two later wells (EE-2 and EE-3) did experience slight losses (175 and 200 bbls) into this formation at 316 m (1037 ft) and 165 m (540 ft). Both zones were quickly sealed off with fibrous bridging agents. Lenses of red clay within the Abo Formation caused a considerable increase in viscosity of the drilling fluid (usually a 40- to 60-s rise in funnel viscosity) when hydrated. The method used to control viscosity and mud weight was simple dilution since adequate water and reserve-pit space was available.

By far the most troublesome and severe loss of drilling fluids occurred in the cavernous-limestone portions of the Madera and Sandia Formations (Fig. 6). Voids encountered in the cavernous Sandia at about 616 m (2350 ft) ranged from 1 to 5 m (3 to 16 ft) in height. Two loss zones required considerable time and effort to overcome the urgent and continuing problems. The loss zone within the Madera Formation was variable in severity for the four wells. Table VII records the quantities of materials used in attempts to control the

TABLE VII

LOST-CIRCULATION MATERIAL SUMMARY

	GT-2	EE-1	EE-2	EE-3
Cement (sacks)	3000	500	5000	3500
Lost Circulation Material (bbl)	1600	8300	3500	2300

lost-circulation problems. In EE-3 a 1-m (3-ft) cavern was encountered at 576 m (1890 ft). The resultant sloughing of the Abo and Madera Formations was almost identical to that experienced in GT-2. Finally the 50.8-cm (20-in.) casing was set at 482 m (1580 ft) to seal off the Abo and upper Madera loss zones.

The cavernous portion of the Sandia Formation is at the bottom of the Magdalena Group and is located about 15 m (50 ft) above the contact with the basement crystalline complex rocks (Fig. 6). All four wells at Fenton Hill encountered this cavernous limestone and no remedial efforts attempted succeeded in regaining circulation.

Several different techniques had been used in attempts to restore circulation in the Sandia Formation. The use of air mist and the use of a "gel" foam were tried without success in GT-2. Both approaches restored circulation temporarily, but neither provided enough hydrostatic pressure to prevent sloughing of the exposed shale sections. This sloughing caused repetitive reaming, large volumes of fill on trips and the sticking of the drill string. Attempts to bridge the cavern with lost-circulation material (15 700 bbls with up to 60% by volume lost-circulation material), gunk squeezes (300 bbls) and massive cementing efforts (a total of 12 000 sacks on all four wells) all proved futile. The plan finally adopted was to minimize the amount of open hole exposed by choice of casing program when the cavern was first encountered. As soon as full returns were lost, the plan was to drill without returns into the basement complex and then set intermediate casing. This program was adopted for EE-2 and EE-3. The casing program in both EE-2 and EE-3 was to run the 20-in. surface casing near the top of the first troublesome loss zone at about 580 m (1900 ft) and then drill through both loss zones without returns as rapidly as possible and then into the basement complex. In both wells this intermediate casing string of 34.0-cm (13-3/8-in.) was set only after some reaming and washing through bridges and fill.

No totally problem-free method has been devised to overcome the loss of circulation in this cavernous zone. The plan to drill EE-3 without returns was successful, but was costly due to the necessity of hauling water. The local, nearby source at La Cueva was used up and delays occurred when water hauling from Los Alamos was necessary. The intermediate casing was successfully run and cemented in a two-stage procedure that assured a 45-m (150-ft) anchor into the granite and, after tensioning, provided a cement sheath behind the casing from 428 m (1403 ft) to the surface. However the zone from 428 m to 693 m (1403 to 2275 ft) was uncemented (see Fig. 7) and no solution has as yet been perfected to avoid this situation.

B. Crystalline Rock

The remainder of the hole was drilled in a Precambrian metamorphic and igneous crystalline rock-complex. Drilling fluid related problems with this portion of EE-3 were extreme abrasiveness, high temperatures [280°C (550°F)], and some areas of apparent permeability. Due to the inclination of the hole (35° from vertical), and the fact that clear water was used as the primary circulating fluid, a combination of the large circulating volume used and the abrasiveness of the metamorphic and igneous rocks caused special torque-reduction problems. The best lubricating agent tried was a mixture of triglycerides and alcohols. The effects of the lubricant was temporary at higher temperatures [>190°C (>375°F)]. Therefore, the lubricant had to be constantly replenished. Furthermore, extremely high torque and drag placed high priority on minimizing drill-pipe failure due to corrosion. Corrosion inhibition was complicated by high temperatures and the circulation of high volumes (15 000 bbls) of water to provide adequate cooling. An oxygen scavenger (ammonium bisulfite) and maintenance of a basic pH successfully moderated this corrosion problem. However, the presence of high sulfur content in the fluid caused a significant problem with bacteria-derived H_2S generated in the reserve pits during the later stages of the EE-3 drilling program. It was also observed that H_2S was generated downhole if the borehole was static for an extended period (e.g., during fishing). This was apparently due to breakdown of the oxygen scavenger and hydrocarbons in the lubricity additives.

The drilling fluids system, fluid cooling, cutting settling, and additive programs were a direct extension of the EE-2 drilling experience. A large reserve pond (approximately 1/2 acre of surface area) was provided to cool the fluid and settle cuttings as it exited from the borehole. The large surface area not only cooled the water effectively, but allowed for ample surface exchange of oxygen. Therefore to prevent pumping water downhole with large concentrations of oxygen, large quantities of oxygen scavenger (ammonium bisulfite) were added to the water prior to pumping downhole in order to remove the oxygen dissolved in the water. A basic pH (9.5 to 10.5) was maintained to further reduce corrosion. Scaling was controlled by the use of a phosphonate compound that removed the cations available for precipitate formation. Results were monitored by corrosion coupons (Table VIII) and revealed that whenever the above treatments were followed, corrosion was kept to a minimum. However, toward the later part of the EE-3 drilling campaign the exterior surfaces and pin-end face seals of the S-grade drill pipe were showing some signs of sharply etched corrosion pitting. This corrosion was assumed to be due to the downhole-generated H_2S and residual oxygen in the drilling fluid. Lubrication of the drill string and BHA is extremely important at the greater depths due to excessive frictional torque and drag generated with the clear water fluid system. The drill string was occasionally subjected to the upper limits of stress recommended by API tables as a result of dog legs produced by the directional drilling in the abrasive basement rocks. The frequent drill-pipe failures that were a direct consequence of these problems resulted in extremely lengthy fishing operations in EE-3. Several methods of lubrication were evaluated and used. The use of granular objects such as walnut hulls or Teflon beads, to reduce torque, was eliminated because of their inability to suspend in clear water and also because of possible bridging effects in future fracturing operations. An oil base drilling fluid was also eliminated because of the high cost of such fluids, the fact that Fenton Hill lies

TABLE VIII

CORROSION RATES ON DRILL PIPE[a]

Well Name and No.	Corrosion Range Observed (lbs/sq ft/yr)
EE-1	0.005 to 1.81
EE-2	0.01 to 5.10
EE-3 (to date 11/22)	0.20 to 3.90

[a]From corrosion monitoring rings installed in the drill string (NL-Baroid).

within an area of environmental sensitivity, and temperature degradation above 200°C (400°F). A biodegradable, soluble chemical added to the water was therefore selected as the best possibility for providing acceptable torque and drag reduction.

An additional limitation was placed upon the lubricating additive due to the high downhole temperatures. Several soluble chemicals were tested in the laboratory but only two were found suitable to test downhole (Table IX). The best additive was a conventional agent that consisted of modified triglycerides and alcohols. The effect of the lubricant was found to be only temporary in the hottest bottom-hole sections of the well. Therefore the lubricant had to be constantly replenished while drilling. This was accomplished by batchwise additions of the chemical. The use of this chemical additive succeeded in reducing excessive wear to the drill string and surface equipment. It also allowed more load to be placed on the cutting surface of the bit rather than the side of the borehole.

A serious problem with this lubricity agent was the tendency to degrade downhole due to temperature. The degraded residue apparently combined with pipe scale, cuttings, and pipe dope to form a heavy "black gunk" that coated the BHA, logging tools, and the borehole walls. Use of a high pH (pH = 12.5)

TABLE IX

DRILLSTRING TORQUE AND DRAG REDUCTION LUBRICATING AGENTS DETERMINED IN EE-2 DRILLING PROGRAMS

Additive & Concentration	Torque (amps) Before	Torque (amps) After	Duration
2 ppb[a] oil base lubricant	600	450	30 min
1 ppb oil base lubricant plus 1 ppb triglycerides & alcohol	600	500	1 h
2 ppb triglycerides and alcohol	600	400	2 h
20 ppb bentonite	600	550	30 min

[a] Pounds per barrel.

and a surfactant (detergent) was required to dissolve and flush out this material in EE-3. The reservoir section was mechanically scraped in an attempt to loosen the material prior to flushing and displacing with clean water.

C. H_2S Difficulties

In the later stages of the EE-3 drilling operation, first noted on day 362, the bacteria in the reserve pits started to produce H_2S. The diagnosis was made that anaerobic bacteria in the bottom slime were converting the sulfur compounds (used in the drilling fluid to control corrosion) to H_2S. Conditions of low oxygen content, warmth, organic residues (from the lubricating additive) and gel (bentonite) sweeps were ideal for their growth. Solution of this problem required the dredging of the pits, use of a treatment with biocides, and strict sulfur control through use of additions of iron sponge and daily monitoring of sulfite additions. Diligent monitoring of H_2S levels, lubricity effectiveness and pH of the fluids was also necessary. Finally an in situ biocide inoculation of the residual bottom slime of the reserve pit was resorted to and held the H_2S production and level to an acceptable value (<5 ppm).

In retrospect, a review of the drilling fluid system approach seems warranted. One approach would consider use of cooling towers, cuttings-removal filters and a nitrogen-based corrosion control method. The major problem would be to remove effectively and practically in the field the very fine cuttings. Another approach would be to continue to circulate the reserve pits, but substitute a nitrogen purge oxygen-scavenger system to replace the sulfur based chemistry. Overall costs would dictate the future choice and selection of an improved drilling fluid system.

V. DRILLING PROBLEMS AND SOLUTIONS

The problems encountered in the drilling of EE-3 were severe but not abnormal for such a high-temperature deep-drilling operation. The drilling history of Fig. 3 is laid out in the diagram in Fig. 10. Two major and three minor problem areas are identified. These problems and their solutions represented over 50% of the time required to drill EE-3--about 235 days of the 461 total. Two major time-increments for fishing and sidetracking are shown and represent 86% of the problems that plagued the drilling campaign. The fishing episodes derive from twist-offs or washouts of the BHA or drill

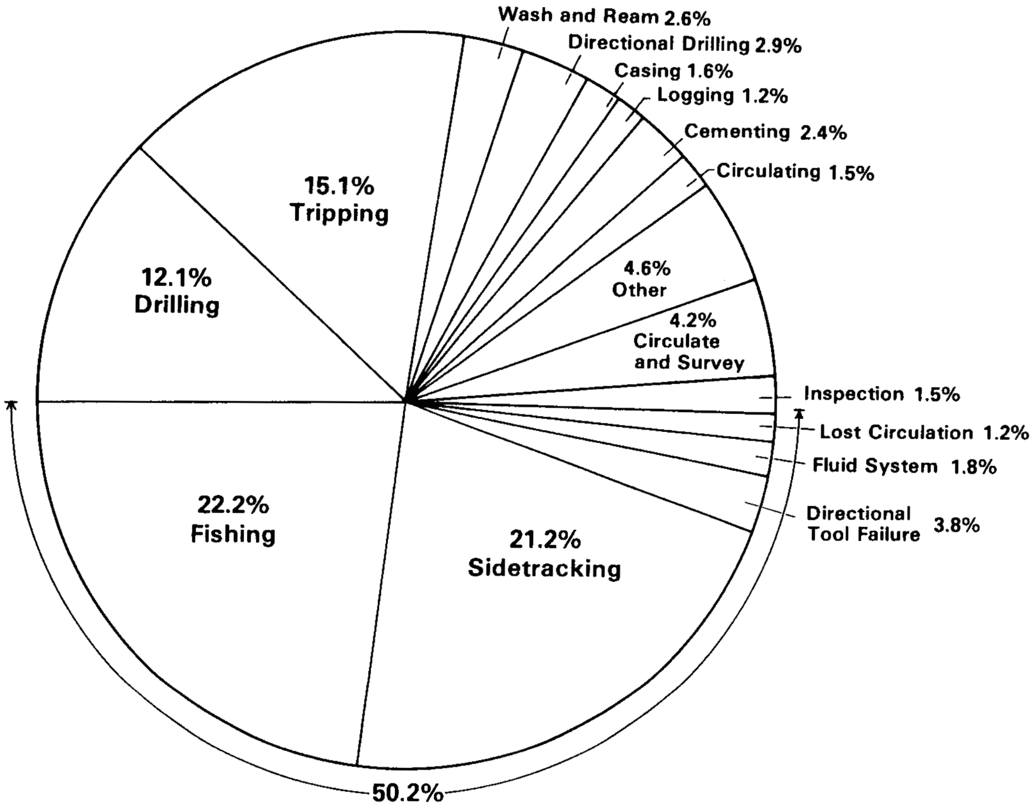

Fig. 10.
Percentage of EE-3 time spent in drilling operations and solving problems.

string. These failures required in turn that the BHA and drill string remaining downhole must be removed or retrieved (fished) from the well. (Note: fishing can also occur when an object falls into the well.)

A. Drill-String Failures

A twist-off in drill pipe is defined as the parting, separation or breaking of a joint [10 m (30 ft) length] of drill pipe by the forces (torque and tension) applied to the drill pipe. The number of stress cycles, or fatigue, can also cause twist-offs. Several of the drill pipe and BHA failures in EE-3 have been referred to as "twist-offs" but do not fit the strict definition. The largest number of failures encountered were washouts in the drill collars (that also often resulted in fishing operations). A washout is usually defined as a crack in the tube or thread of a connection that is washed or eroded by drilling fluid and results in a strength reduction in the component (drill pipe, collar, or other BHA member). Usually a washout will erode away slowly up to 2/3 of the total metal in the cross section, at which point the remaining metal will mechanically fail by torque or tension loadings.

Table X is a comparison between EE-2 and EE-3 of the four different major types of drill-string failures. There were four times as many drill-string failures in EE-3 operations as compared to EE-2. The majority of the failures in EE-3 were in the BHA, but the most severe and the longest delays were caused by drill-pipe failures.

There were five twist-offs in EE-3 compared to none in EE-2. The first two were twist-offs of the tube on the 12.7-cm (5-in.) drill pipe. The second of these twist-offs caused the longest (unsuccessful) fishing job and eventually required a sidetrack of the hole.

The 12.7-cm (5-in.) drill string was laid down, returned to the drilling contractor, and an 11.4-cm (4-1/2-in.) string was substituted during these fishing operations. It was felt that the 12.7-cm (5-in.) string was badly fatigued during the drilling of EE-2 and initial drilling of EE-3 and continued use would only result in more-frequent fishing operations. An evaluation of the two fractures in the pipe indicated severe corrosion pitting (see Fig. 5). A detailed post-failure analysis[17] of the fracture confirmed that fatigue was responsible for the fracture.

The remaining three twist-offs occurred in the 11.4-cm (4-1/2-in.) drill pipe. In each of these cases, the threaded pin on the tool joint cracked and failed (there was no fluid washing involved).

TABLE X

COMPARISON OF EE-2 AND EE-3 DRILL-PIPE AND BHA FAILURES

Type Failure	EE-2	Remarks	EE-3	Remarks
Washout without fishing operation	4	2 in BHA 2 in drill-pipe tube	11	10 in BHA 1 in drill-pipe tube
Washout with fishing operation	1	Pipe-tube washout while drilling (fell apart on trip out)	4	All in BHA
Twist-off	0	-	5	2 in 5-in. tube 3 in 4-1/2-in. pin
Parted string	1	Crossover sub fell apart while tripping in the hole (pin end)	3	1 in 5-in. tube 1 in 4-1/2-in. pin 1 in accelerator
Totals	6		23	

There were also three drill-string failures during EE-3 drilling operation where the drill string was pulled apart. The first one was in the 12.7-cm (5-in.) drill pipe. The tube of the pipe failed well below the API minimum tensile strength. The failure added 31 days to the total fishing operations. The next failure occurred while jarring on a fish. An accelerator used in the fishing BHA to enhance the effect of the jars, was pulled apart. The third parting failure occurred while making a connection. The threaded pin on a tool joint pulled apart at loads far below the API specified minimum tensile strength. It was assumed that the pin had been cracked resulting in the premature failure.

The EE-3 drill-string failures that caused the greater time delays were: (1) the twist-off of the 12.7-cm (5-in.) tube while reaming to bottom, (2) the parted drill pipe while jarring on a fish, and (3) the twist-off of the 11.4-cm (4-1/2-in.) drill-pipe connection (pin) while reaming to bottom. The four washouts resulted in fishing operations that caused only short delays.

Two procedures or practices were used to minimize, or guard against, drill-string failures. Drill-pipe inspections were regularly conducted every 30 days or 500 rotating h, whichever came first. This practice was routinely followed after the 12.7-cm (5-in.)-diam drill string was replaced. A second measure instigated was to have a complete second alternate, 11.4-cm (4-1/2-in.) string on site. This allowed one string to be laid down and inspected while the second string (previously inspected) was run in and drilling continued. This saved 4-1/2 days of the 5 to 6 days of downtime usually required for an inspection. More importantly, it allowed more time and care during the inspection, thus making it more likely that flaws and incipient failures were detected. This is especially important during difficult weather conditions.

During the final bit runs the added precaution was instituted of rig-floor inspection of all tool joints (pins and boxes) of each drill-string section or joint as it was being added. This procedure detected and rejected three cracked pins, perhaps avoiding a recurrence of the final twist-off that occurred on day 438.

The less-frequent drill-string failures in EE-2 was probably due in part to the lower DLS of that well as compared in Fig 11. It is important to monitor and control the DLS during directional drilling operations and to hold DLS to less than 2 to 3° per 100 ft maximum. It is particularly important to avoid the sharp s-curved crooked hole condition generated in EE-3 in the 1980 to 2190 m (6500 - 7200 ft) interval and the 2960 to 3200 m (9700 to 10 500 ft) zone in the original drilled portion of the 31.1-cm (12-1/4-in.)-diam hole. A strict dogleg minimization strategy is particularly important because even very extensive and intensive reaming with an extremely stiff BHA (e.g., two six-point reamers back-to-back) is of limited effectiveness in reducing such crooked hole conditions in crystalline rocks.

B. Sidetracking

On October 28, 1980, day 160, a twist-off occurred in EE-3 while drilling the 31.1-cm (12-1/4-in.) hole at a depth of 3200 m (10 528 ft). Fishing continued until December 15, when the sidetracking operation was initiated to bypass the stuck BHA. Figure 12 records the EE-3 configuration for the side-tracking operations. The hole was underreamed to a 40.6-cm (16-in.)-diam from 2975 to 2979 m (9760 to 9774 ft) and from 3013 to 3016 m (9885 to 9900 ft).

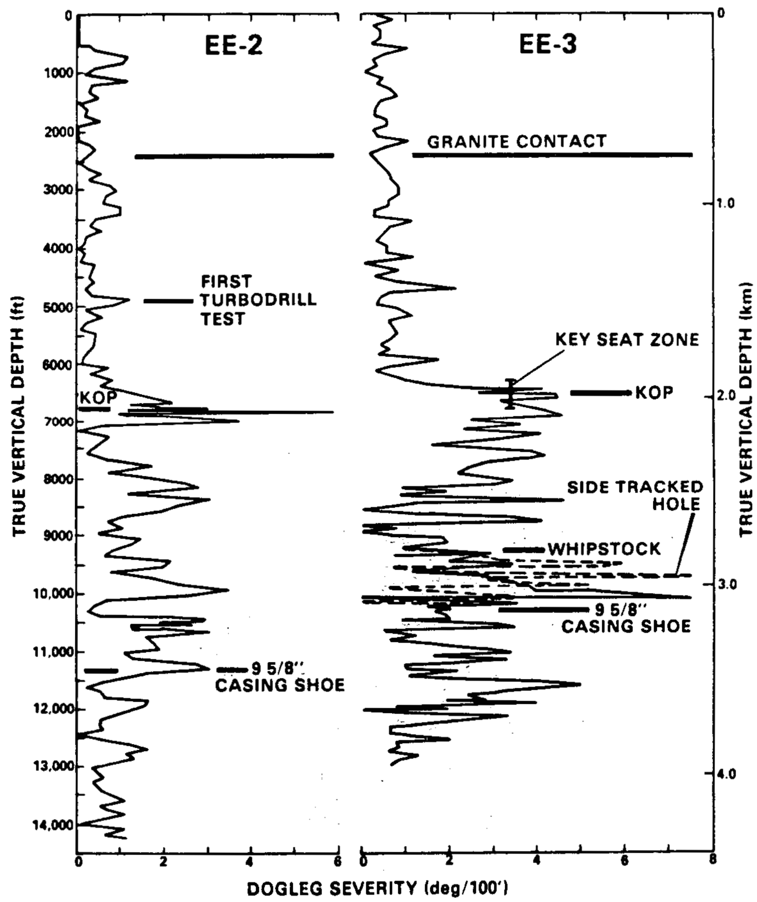

Fig. 11.
Comparison of EE-2 and EE-3 DLS.

Six cement plugs were set before a plug with satisfactory hardness was placed. The penetration rate while facing off the first five plugs was about 0.3 m/min (1 ft/min) at 22 x 10^3N (5 000 lb_f) bit load; the sixth plug was drilled at 0.1 m/min (0.3 ft/min) with 45 x 10^3N (10 000 lb_f) bit load (see Table I).

Two Dyna-Drill runs with a Smith 25.1-cm (9-7/8-in.) Q9JL TCI bit and 2° bent sub were made in plug No. 6 to 2981 m (9780 ft), at a penetration rate of 2 m/h (7 ft/h) and bit load of 9 x 10^3N (2000 lbs), without any indication of weight increase or sidetracking action.

An attempt was then made to run a 30.5-cm (12-in.)-o.d. whipstock, but the whipstock started to drag at about 2070 m (6800 ft) and would not go past the DLS portion of the hole near 2195 m (7200 ft). To avoid shearing the shear pin holding the whipstock to the drill string [set for 111 x 10^3N (25 000 lb_f)], the whipstock was not forced and was subsequently pulled from the hole.

While a 26.7-cm (10-1/2-in.) whipstock was being built, another attempt was made to sidetrack off a cement plug. A gamma-ray log located an altered or fractured zone higher in the hole, where it was presumed that the softer rock might offer a better chance for drilling out. This zone was underreamed to 41-cm (16-in.)-diam from 2833 to 2844 m (9293 to 9330 ft). The eighth cement plug (Class J Cement) was placed and a sidetracking assembly was used that consisted of a 22.2-cm (8-3/4-in.) TCI button bit, a Dyna-Drill PDM with 2° bent housing, and a 2° Dyna-Flex. Drilling through the underreamed section progressed at a timed rate of 0.3 m/h (1 ft/h) with no load. After drilling 1.3 m (4 ft) the assembly was picked up 3 m (10 ft) and reamed slowly back to bottom. Three button bits and one sidetracking diamond bit were used in six separate motor runs in which a total of 24 m (78 ft) was drilled. It appeared that the diamond bit had started to sidetrack at the bottom of the underreamed section, because the load on the bit increased from 4 x 10^3N (1000 lb_f) to 65 x 10^3N (15 000 lb_f) while the penetration rate of 0.3 m/h (1 ft/h) remained constant. Two TCI button-bit runs following the diamond bit also indicated that sidetracking had been started, both from the wear pattern on the bits and increased percentage of granite chips in the cuttings. Assuming that a side-track had been established, an angle building assembly was run in, but continued drilling produced only cement cuttings, indicating continuation in the old hole.

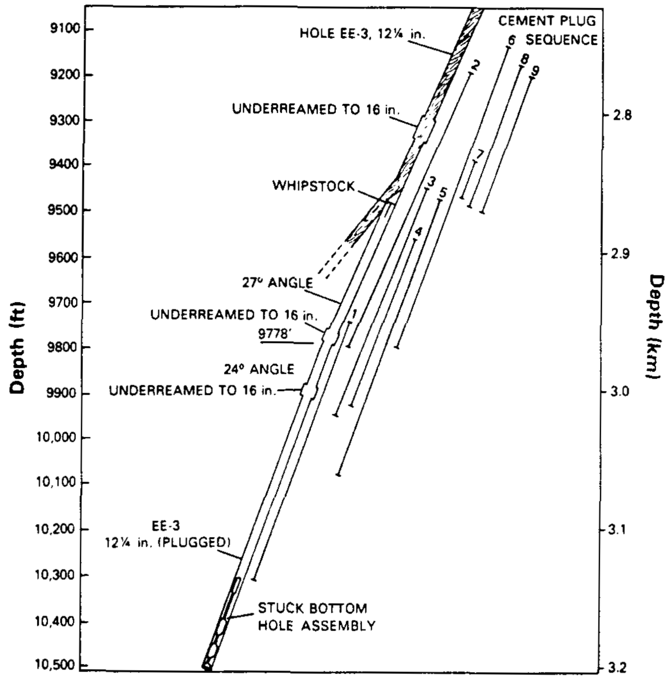

Fig. 12.
Diagram of EE-3 sidetracking operations (see Table I).

A 27-cm (10-1/2-in.)-o.d. whipstock, Fig. 13, with a 3-m (10-ft) slide designed with curvature to accommodate a 31.1-cm (12-1/4-in.) bit was run in with 10 m (30 ft) of tailpipe below, and was oriented and cemented with the ninth cement plug. The top of the whipstock was set at 2879 m (9444 ft). The top of the whipstock-anchoring plug was at 2804 m (9200 ft) to allow another chance at sidetracking in the underreamed section. Various slow time-drilling penetration rates were tried at the underreamed zone in drilling down to the whipstock using button bits on a Dyna-Drill PDM, but sidetracking was not accomplished.

Junk was encountered at 2875 m (9432 ft), about 3 m (10 ft) above the top of the whipstock while drilling cement down to the whipstock located at 2879 m (9444 ft). The junk was cleaned up through a series of bit, mill, and magnet runs*. The junk was determined to be a high-chrome steel piece perhaps 1- to 1.2-m (3- to 4-ft) long, and not the cast steel of the whipstock. A BHA consisting of a 31.1-cm (12-1/4-in.) Q9JL bit, one 17.1-cm (6-3/4-in.) drill collar, jars, and 15 joints of HWDP was used to drill off the whipstock.

*About 2/3 m (2 ft) of junk was actually drilled up with a TCI bit, a Smith Tool Co. Q9JL bit.

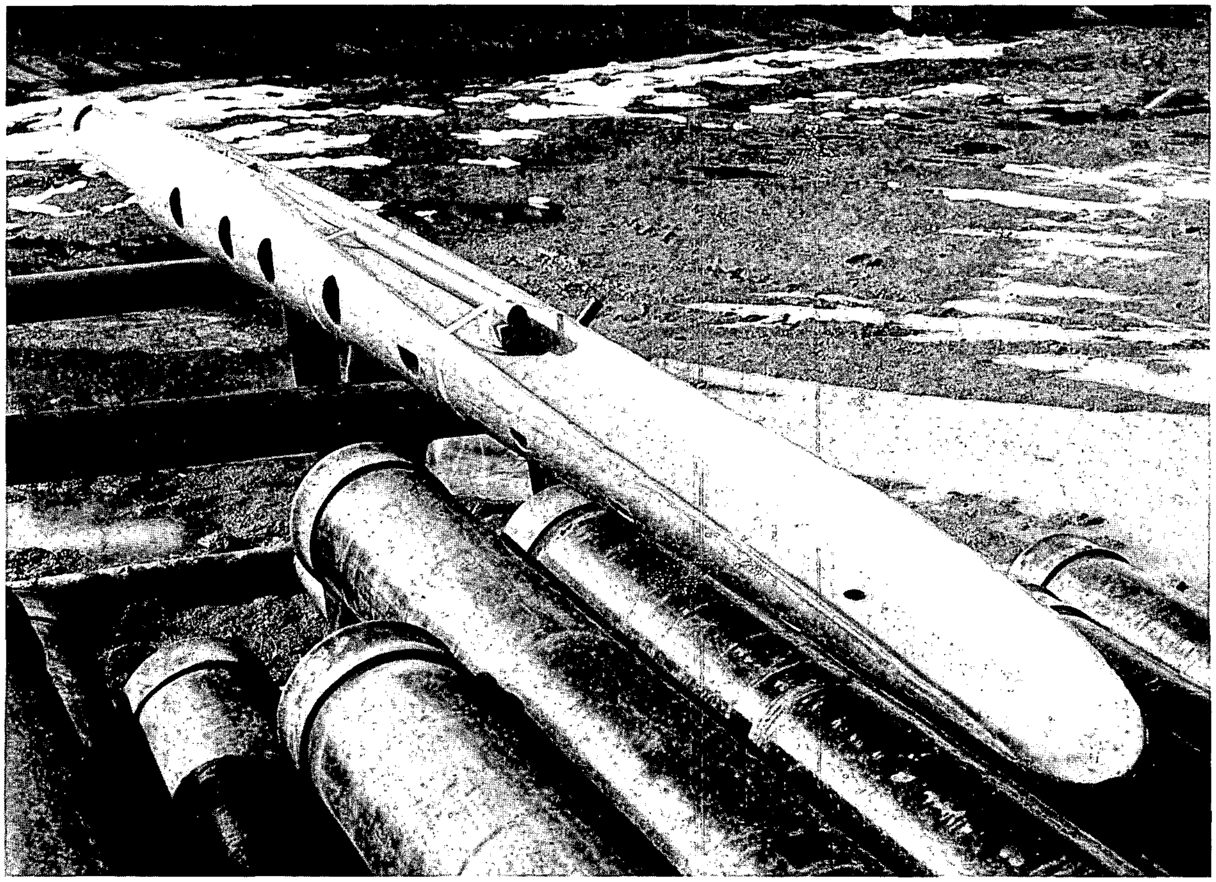

Fig. 13.
Photograph of 10-3/4-in.-diam whipstock.

The bit drilled 5 m (15 ft) in 15.5 h with 22 x 10^3 to 67 x 10^3N (5000 to 15 000 lb_f) bit load. As the amount of granitic chips in the cuttings was increasing steadily, an angle-building assembly was made up and 30 m (97 ft) of new hole were drilled, which definitely established the successful sidetrack on March 22, after three months of attempts.

In retrospect, considering the ease that the 31.1-cm (12-1/4-in.) button bit finally drilled off the whipstock, it would seem that any further sidetracking attempts in similar situations should consider using a whipstock as the initial attempt. Either permanent or temporary tools might be considered. If a large number of bit runs or trips must be made past a whipstock, the permanent, cemented-in-place variety, would appear to be the better solution. Use of cement plugs and underreaming, a technique used routinely in soft and medium-hard formations, would seem of limited value in HDR wells, even though GT-2 was previously sidetracked twice by these techniques.[10] Current

Portland-cement-based plugs, at least, seem a poor basis upon which to plan a sidetracking operation in granite, or other very hard formations. Research work on a more reliable, and far harder (harder to drill) "cement"-like material for such sidetracking applications would seem appropriate and might improve the odds of sidetracking by this method. Effective alternate side-tracking methods (and alternates for any other particular drilling or remedial operation) are always a distinct benefit to drilling success.

C. Keyseat.

The section of the 31.1-cm (12-1/4-in.) hole from about 1980 m (6500 ft) to 2195 m (7200 ft) caused several problems during the drilling of EE-3. A keyseat is assumed to have been formed, centered at about 1980 m (6500 ft) depth. At least a keyseat would explain the problems encountered in this section of the well. The usual description of a keyseat is a channel or vertical groove cut in the high side of an inclined hole by the drill-string rotation and drag. The groove is worn parallel to the axis of the hole. Key-seating of the BHA or drill pipe occurs when the larger o.d. BHA or a drill-pipe tool joint is pulled up into the channel cut by the drill pipe or drill-pipe connections. A dogleg or sharp turn in a hole must be present for a keyseat to form. A keyseat does not restrict drilling fluid circulation. A sketch of a keyseat is shown in Fig. 14.

The directional drilling in EE-3 started at 1964 m (6444 ft). At the KOP the first PDM directional drilling run was attempted using a 2° bent sub. Instead of using a steering tool, the single-shot instrument was used to orient the directional assembly. With the single shot, there is no continuous readout of tool orientation at the surface; therefore, use of the single-shot survey does not monitor the borehole trajectory as it is drilled, as in the case of a steering tool. In these first two directional drilling motor runs, the hole went from 10°N58°W at 1923 m (6431 ft) to 14-3/4°N42°W at 2030 m (6662 ft). In this section the SDL averaged 3.6°/100ft and was as high as 5.6°/100 ft (see Figs. 4 and 11). It was obvious that the downhole motors could not be sufficiently well monitored with the single-shot tool and the EYE steering tool was used after the second run (see Table III). Directional drilling continued with downhole motors with the primary object to turn the hole azimuth. During the following directional drilling sequences the desired azimuthal correction was achieved, but a severe drop in inclination also occurred. The survey data went from 14-3/4°N42°W at 2030 m (6662 ft) to

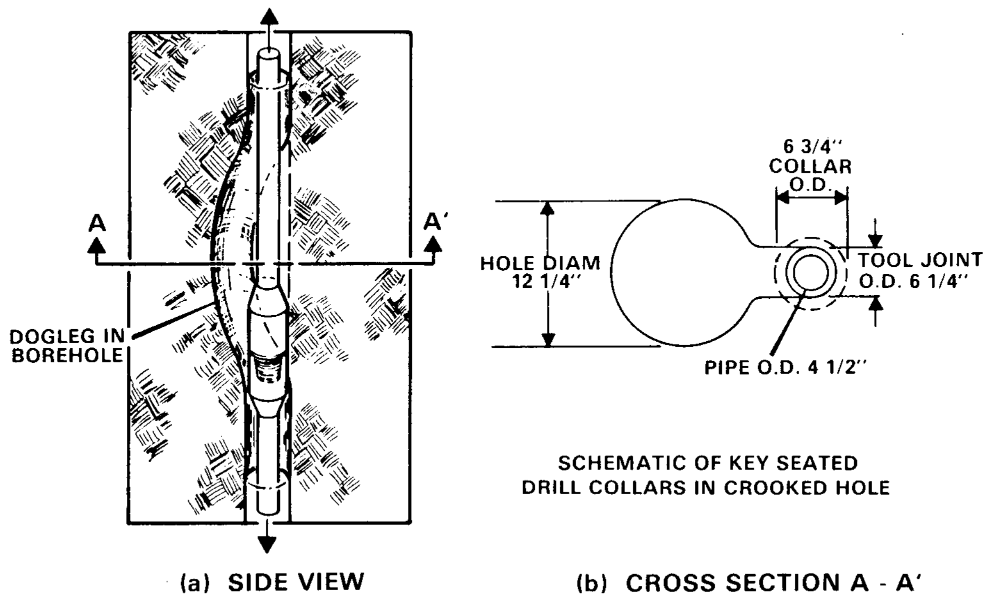

Fig. 14.
Schematic of keyseat.

8-1/4° N63°E at 2260 m (7400 ft). The DLS averaged 3.8°/100 ft. The resulting "S"-shaped portion of the wellbore had established the conditions for a keyseat to form. The many hours of rotary drilling and many trips below this crooked-hole zone provided the cutting mechanism for the keyseat channel by both drill pipe and (especially) the hardbanded connections.

The keyseat did not present any problems until the first 22.2-cm (8-3/4-in.) bit was run on day 350 with 17.1-cm (6-3/4-in.) collars. This was due to two factors: (1) The previously used 20.3-cm (8-in.)-o.d. drill collars were sufficiently large to keep them out of the smaller-diameter keyseat channel cut by the 16.5-cm (6-1/4-in.) pipe connections. The 17.1-cm (6-3/4-in.)-o.d. collars were not large enough and they wedged in the keyseat channel. (2) The 17.1-cm (6-3/4-in.)-o.d. collars are more flexible. Because there were 11 17.1-cm (6-3/4-in.)-o.d. collars in the BHA, the top collar tended to ride the high side of the hole where the keyseat channel was located.

The two times that the drill collars were stuck at approximately 1980 m (6500 ft) the drill string was being pulled out of the hole. In each instance the collars were jarred and worked loose downward, and then worked upward past the keyseat. Also, there was no problem circulating past the stuck-point when the BHA was stuck in the keyseat channel.

After the second time the BHA was keyseated, string reamers were run to increase the diameter of the keyseat channel to 22.2 cm (8-3/4-in.)

The single-arm caliper log (Fig. 15) shows a diameter greater than 50.8 cm (20-in.) (the caliper arm is at the maximum extension) between 1980 m and 2010 m (6500 and 6600 ft), so the lateral extent of the keyseat was not determined.

Therefore all available data points to the formation of a keyseat in the wellbore in the 1980 to 2010 m (6500 to 6600 ft) interval.

D. Elastomer Seals. The temperature limits of commonly used elastomeric seals contributed to failures, or life reduction, of many downhole tools and instruments. Unsealed drill bits that do not depend on sealed lubricant in the bearings must be selected. Lubrication and cooling by drilling fluid containing cuttings obviously reduces bit bearing life.

Other necessary BHA components--drilling and fishing jars, shock absorbers, over-shot fishing grapples, and PDM motors--depend upon elastomers. At temperatures above about 165°C (350°F) many of these elastomers fail or degrade rapidly.

One major problem area encountered was due to the failure of seals used on near-bit float (check) valves. These valves are included in the BHA near the bit, usually in a float sub, to prevent back flow of drilling fluids and cuttings up the drill-pipe i.d. This most often occurs when a joint or stand of pipe is added to the string, and is due to the excess weight of the cuttings carried in the drill pipe-to-wellbore annulus. This is in turn caused by the limited cuttings-carrying capacity of the clear-water drilling-fluid system. The U-tube effect of the higher density annulus fluid then carries cuttings into the BHA, often plugging collars and downhole motors. This plugging usually cannot be cleared by the rig pumps and requires a time-consuming round trip out of the hole. The cleaning of the plugged collar often required a trip to a shop in Farmington, New Mexico. The plugged-motor occurrences were especially disruptive as the steering tool had to be rigged down and then re-rigged after the motor was changed out. Disassembly, cleanout, and rebuild of the MEI turbodrills was always necessary because the unsealed bearings invariably plugged when the float valve failed.

A solution to the float-valve-seal problem was initiated during the drilling of EE-2. The float-valve supplier (Barkerline, San Antonio, Texas) was contacted and initiated a development to replace the standard elastomer

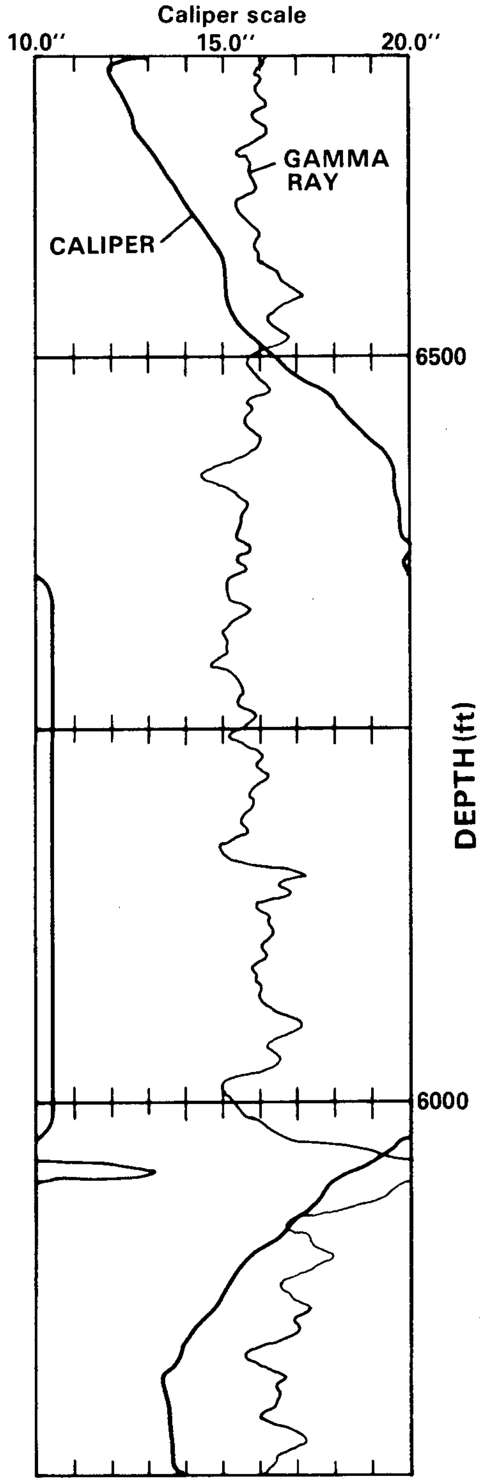

Fig. 15.
Single arm caliper log showing keyseat zone.

seals, Fig. 16, with a high-temperature material. After several prototype runs by several elastomer suppliers, an EPDM formulation provided a seal that tested successfully in the Los Alamos autoclave, for 30-to-40-h rotary-drilling runs and for the 3-to-5-h turbodrill runs; all to at least 280°C (550°F). In addition a strategy that employed two float valves in tandem, one in the top turbodrill sub, and one in a float sub above the turbodrill, gave added insurance against the float valve failures on the directional motor runs.

The solution of the elastomer-seals problem was the application of an EPDM formulation and was aided and guided by the recent successful U.S. DOE funded R&D project by L'Garde, Newport Beach, California.[18,19] It may help point the way toward solutions to high-temperature elastomer problems in other drilling components.

E. Wireline Tools. Nearly all wireline-deployed tools are severely limited in high-temperature performance. A generic problem exists in cable heads and cables, and is a recognized problem throughout the geothermal industry. Problems with diagnostic logs such as calipers, gamma surveys, casing inspection, and cement-bond evaluations result

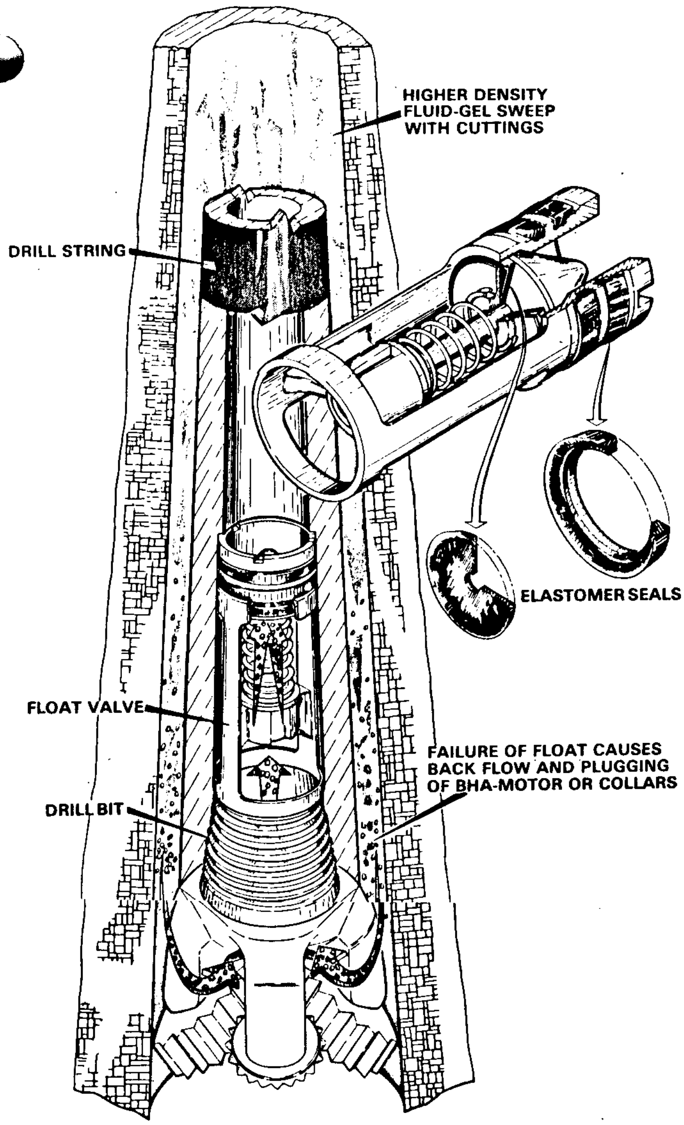

Fig. 16.
Float-valve-seal function in drill string.

from temperature limitations and are often plagued with poor quality and unreliable performance. Fishing tools such as free-point surveys, perforators, back-off shots, and pipe-severing services are also affected. These operations often require repeated attempts, lose effectiveness when successful, and may require extended cooldown by lengthy circulation. High-temperature detonators are a definite need, and a problem needing solution for all geothermal fishing operations.

The directional-drilling steering-tool problem had been tackled in EE-2 by Scientific Drilling Controls (Irvine, California) and a special hot-hole cable, cablehead and, dewar-protected downhole-electronics system afforded adequate steering-tool performance for the azimuthal corrections in the deep, hot reservoir section of the 27.2-cm (8-3/4-in.)-diam borehole of EE-3.

F. Cement Plugs. Portland cements for high-temperature oil, gas, and geothermal wells have been recognized as a major problem.[20] Use of cement plugs for effective and reliable sidetracking operations in extremely hard, crystalline rocks will require a considerable effort in a search for a "cement" that will drill hard relative to a granite formation. That is because a side tracking bit must take a relatively high bit-load to generate sufficient side-cutting force and action to groove the sidewall. Low-penetration rate to effect an efficient grooving action is required and this in turn requires a slow drilling rate. Thus an extremely hard plug is required. Development of special types of side-cutting bits, i.e., especially designed diamond bits and skewed-axis three-cone bits would be valuable.

One further comparison is given on Table XI where the various types of drilling problems and troubles for EE-3 (and EE-2), and the nearby Baca hydrothermal drilling operations (conducted by Union Geothermal Div.), are tabulated as the percent of total time required to solve the particular problem expressed in percent of total drilling time spent solving all the problems. The noted differences are about as expected, with hydrothermal drilling experiencing more lost-circulation and stuck-pipe (formation caving and sloughing into well that traps the drill string or BHA) problems than the deeper hot dry rock drilling. The directional-drilling problems are not encountered in the Baca hydrothermal wells because no azimuth control has been required there.

VI. DESIGN AND INSTALLATION OF THE PRODUCTION CASING STRING

A. Casing Design

The unexpectedly high bottom-hole static reservoir temperature potential achieved by EE-2 [275°C (550°F) projected vs 320°C (608°F) measured], the actual DLS, and desirability of supression of wellhead growth during production, required a review of the EE-3 production casing design and cementing plan. The result of the review was a decision to replace the original 24.4-cm (9-5/8-in.)-o.d., 59.6 kg/m (40 lb_m/ft), S-95 and N-80 grades, buttress-thread-connection casing string with a heavier-weight, premium-connection, higher strength steel string. This design change was judged to provide a greater margin against collapse and coupling-connection failures, and a longer life relative to wear and corrosion.

The selected replacement, a choice dictated partly by availability, was a 70.0 kg/m (47 lb_m/ft), VAM connection, P-110 grade casing. This heavier casing would restrict tools and bits to a 21.6-cm (8-1/2-in.) maximum diameter.

The change in cementing plan was based upon a two-stage cementing procedure. A high-strength, low permeability, and high-temperature-curing cement was formulated for the bottom 1000 m (3000 ft), as the first stage. A stage cementing valve (DV tool) was included at the top of the first stage and a second stage of lightened (low-density) cement was to be placed above the stage collar (DV tool) and designed to extend up to a depth of 1000 m (3000 ft). This strategy would provide lateral support and stability to the upper portion of the casing in the deviated hole section, yet provide approximately

TABLE XI

COMPARISON OF RELATIVE PERCENTAGE OF TIME REQUIRED TO SOLVE VARIOUS MAJOR PROBLEMS BACA, EE-2, AND EE-3

Type of Problem Solved	Percentage of Time Required to Solve Problem, %		
	BACA	EE-2	EE-3
1. Lost circulation	14.3	6.9	2.4
2. Stuck pipe	26.9	--	a
3. Twist off	2.7	15.5	11.9
4. Sidetrack	12.6	--	30.2
5. Rig/Fluid Problems	5.1	4.9	3.6
6. Casing problems	19.5	63.4	a
7. Cementing Problems	13.4	a	12.0
8. Fishing & Junk	5.5	5.5	32.3
9. Directional Problems	--	2.3	7.6
	100	100	100

[a]Less than 1%.

150 m (500 ft) of exposed open borehole to relieve any buildup of annulus pressure. A tension load of about 40 x 10^5N (900 000 lb_f) was designed to pre-stretch the casing sufficiently to compensate for about one-half of the expected thermal growth. The welded and sealed wellhead would then be designed to contain the expected thermal growth with a hold-down force of about 20 x 10^5N (450 000 lb_f). Figures 7 and 17 summarize the final EE-3 casing configurations and cementing program.

B. Installation of the Production Casing

1. Summary Chronology. Total depth was reached on August 7, 1981 (day 443) and cleaning of the wellbore started as soon as the last bit run and single-shot survey were completed. Initial cleaning of the wellbore was completed on August 8 and the logging of the well began that same day and continued into August 9. The logs were finished on August 9 and the first cement plug was placed later that same day. This plug was placed to prevent

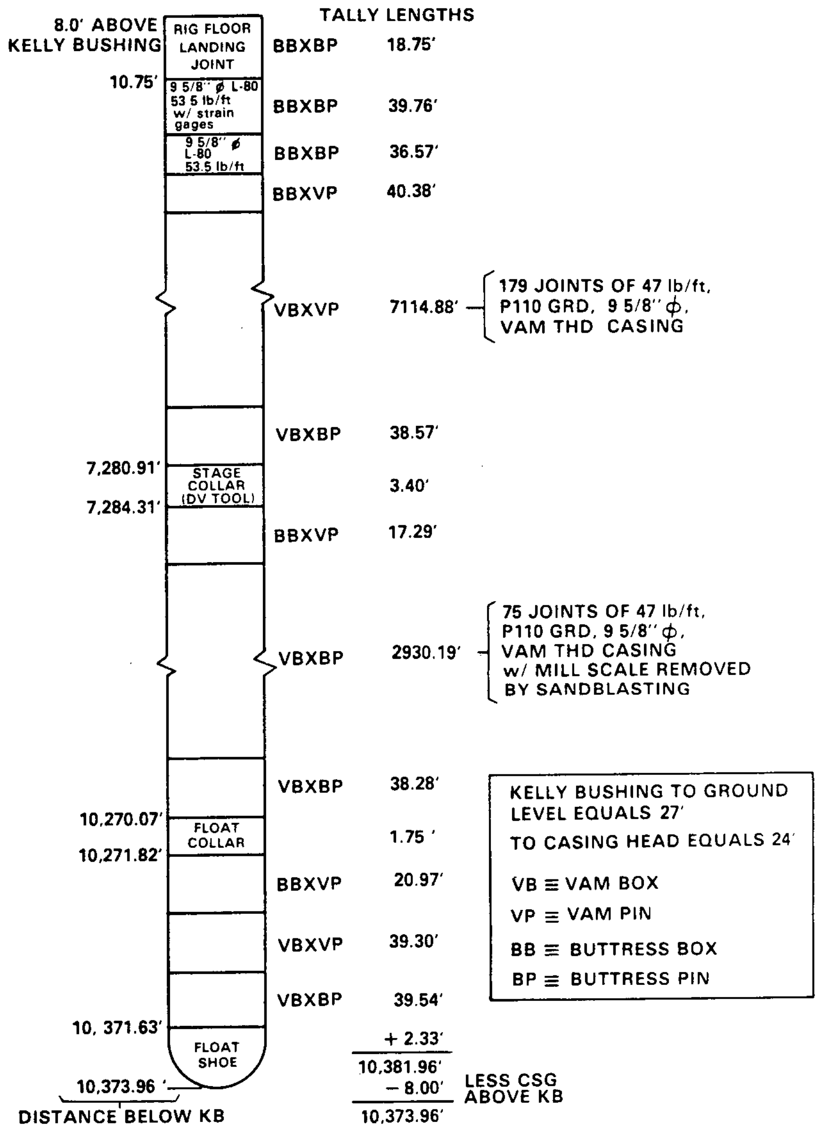

Fig. 17.
Details of 9-5/8-in. casing measured depths from tally.

the first stage cement from sliding down into the 22.2-cm (8-3/4-in.) diam hole. Additional logs were run on August 10 and 11. The second cement plug (the first plug slipped downhole) was placed on the August 12 and was allowed to harden 12 h and was faced off to 3170 m (10 400 ft) on August 13. The casing tensioning jacks were installed and casing run-in initiated on August 14, day 450. The running of the casing was completed on the next day and the first stage of the casing cementing began that same day and was completed the next day, August 16. While waiting on the cement to harden, a temperature survey was made. The casing was tensioned and stretched and the second stage of the casing cementing was completed on August 18. The casing was also landed in the wellhead and cut off on day 454. All operations were conducted as planned, operations proceeded as scheduled and the casing installation was accomplished in an essentially trouble-free manner.

2. Initial Cleaning. Immediately after drilling stopped, two 12 m^3 (75 bbl) gel-mud-sweep pills were pumped downhole through the BHA and drill bit. Each gel pill consisted of 34 sacks of bentonite gel, two sacks of "Benex" polymer and two sacks of caustic soda (to raise the pill pH). Four hours after being pumped downhole the gel-mud-sweep pills were circulated to the surface.

The fluid in the open hole [22.2 cm (8-3/4-in.)] section at the bottom of the well was then displaced with a detergent solution. This was made by mixing drums of concentrated detergent with fresh well water using a ratio of 0.42 m^3 (110 U.S. gal) of detergent to every 16 m^3 (100 bbls) of fresh water. The solution was placed in the hole by sequentially pumping 4 m^3 (26 bbls) of solution, pulling three stands [~30 m (90 ft)] of drill pipe out of the hole, pumping 4 m^3 (26 bbls) more of the solution, pulling 3 more stands of drill pipe, etc. When the bit was at 3350 m (11 000 ft) the balance of the drill string was tripped out. A new BHA that included specially fabricated borehole scrapers was lowered back downhole. The scraper BHA consisted of a 22.2-cm (8-3/4-in.)-diam bit, a short drill collar, two modified stabilizer bodies with a brazed-on, looped cable scraper attached to each body. The scraper assembly was pushed to the hole bottom. The scraper BHA was then pulled up hole to 3295 m (10 811 ft) and then pushed back to the hole bottom, and 102 m^3 (639 bbls) of approximately 2% detergent solution were then pumped into the hole. The scraper BHA was then tripped out of the hole. When on the rig floor, it was noted that the scraper elements had worn badly and some had been left downhole.

3. Cement Plug Placement. The Los Alamos temperature-survey tool was used to determine the borehole temperature and to record temperature-recovery rates.

The drill pipe was tripped in open ended in order to place the cement plug to 3322 m (10 900 ft). Then 3 m^3 (20 bbls) of fresh well water were pumped down hole as a cementing preflush. Next 9 m^3 (58 bbls) of 1980 kg/m^3 (16.5 ppg) cement--consisting of 210 sacks of class H cement, 4.3 m^3 (27 bbls) of fresh water, 20% silica flour, 20% 100-mesh silica sand, 0.75% D-65 turbulence enhancer, 1.4% L-10 and 2-8% D-28 retarder--were mixed and pumped downhole in 16 min. The cement slurry was displaced out of the drill pipe by 23.7 m^3 (149 bbls) of fresh water. The drill pipe was then pulled out of the hole and the cement plug was allowed to harden for 18 h.

When a milled-tooth-bit BHA was tripped in, it reached 3287 m (10 783 ft), at the approximate location of the transition between the 31.1-cm (12-1/4-in.) and 22.2-cm (8-3/4-in.)-diam holes, without encountering the plug. The drill string was believed to be resting on the hole wall in the transition region, which meant that the cement plug had slid toward the bottom of the hole or was mushy and couldn't support drill-string weight. The BHA was kept at 3287 m (10 783 ft) and circulated for 6 h; returns reaching the surface were fine sand. The BHA and drill pipe were then pulled out of the well while an alternate cement plug was formulated. Schlumberger was rigged up to log with gamma ray, compensated formation density, compensated neutron, and one-arm caliper tools. The survey was run up from 3290 m (10 800 ft) to 1000 m (3000 ft) and when the logging tools reached the surface they and the bottom 30 m (100 ft) of logging cable were coated with a gray-green-colored crust that contained cement. Schlumberger then ran a borehole geometry (two-independent-arm caliper and dipmeter) log from 2960 m (9500 ft) up hole to 1800 m (5900 ft) where the tool failed. When the borehole geometry tool reached the surface it was also coated with a gray-green-colored crust that contained cement; there were also indications of this gunk on the bottom 460 m (1500 ft) of logging cable. The caliper logs were intended to provide data for cement-volume calculations. The neutron-gamma log suite was provided to detect water pockets after the cementing was completed, by use of before-and-after log comparisons.

The Los Alamos temperature survey tool was then rerun to measure temperature from the surface to 3290 m (10 800 ft). When a 3290-m (10 800-ft) depth was reached the tool response to temperature became inhibited and tool behavior indicated it was insulated from the borehole environment. The tool was moved up and down the hole in an attempt to clean the tool, but cleaning didn't occur and the tool was pulled out of the hole. When the temperature sonde reached the surface it was again found to be coated with a gray-green wax-like crust. The tool's thermistor was cleaned and the tool was run back in the hole to 2230 m (7300 ft) where it measured a temperature-recovery rate of 4°C/h (8°F/h). The tool was then lowered to 3260 m (10 700 ft) where a temperature of 185°C (370°F) and a recovery rate of 0.5°C/h (0.9°F/h) were recorded. The temperature probe was then lowered further downhole to sound for the cement plug. The tool bottomed at approximately 3295 m (10 810 ft). When the tool was pulled out of the hole it was again found to be heavily coated with the gray-green waxy gunk.

The uncertainty about the competency of the previously placed cement plug dictated the placement of a second plug before running the casing. The drill pipe was lowered open ended into the hole to 3287.9 m (10 787 ft) where the string lost 20 000 lbs of weight. (The string was possibly resting on the first cement plug). The drill pipe was pulled up hole 3 m (10 ft) where 8 m^3 (50 bbls) fresh-water preflush was pumped downhole. Next 6 m^3 (35 bbls) of 1980 kg/m^3 (16.5 ppg) cement slurry was mixed and pumped downhole. The slurry formulation consisted of 144 sacks of class H cement, 3 m^3 (19 bbls) of fresh water, 40% silica flour, 0.75% turbulence enhancer, 0.6% L-10 and 1.2% D-28 retarders. A lightened 1350 kg/m^3 (11.3 ppg) cement slurry was then mixed and 20 m^3 (66 bbls) pumped downhole. The 1350 kg/m^3 (11.3 ppg) cement slurry consisted of 126 sacks of class H cement, 7 m^3 (43 bbls) of fresh water, 7.1 m^3 (252 ft^3) of expanded perlite, 2% bentonite, 40% silica flour, 0.75% D-65 turbulence enhancer, 1% L-10 and 2% D-28 retarders. A tail of 0.5 m^3 (3 bbls) of the 1980 kg/m^3 (16.5 ppg) cement slurry was then pumped downhole as a hard cap for the lightened plug. The cement was then displaced out of the drill pipe with 21 m^3 (132 bbls) of fresh water.

After a 9-h wait, the face-off BHA contacted stringers at 3114 m (10 215 ft), and then the second cement plug was drilled (19-1/2 h after placement) down to 3170 m (10 400 ft). Two 12 m^3 (75 bbls) gel-mud-sweep pills were used to clean the cement cuttings from the hole. A pH = 12.0 was maintained in the drilling fluid while the gel pills were circulating by adding caustic soda.

4. Running Casing. The BOP stack was removed from the rig substructure. Timber sills, the steel support cribbing and casing tensioning jacks were located around the wellhead. Casing handling and torque-turn monitoring equipment were assembled and installed on the drilling rig.

The cementing float shoe, float-valve collar, stage collar cementing tool (DV tool), 24.4-cm (9-5/8-in.) casing string [70 kg/m (47 lb/ft)], and two landing joints of 80 kg/m (53.5 lb/ft) L-80 grade were picked up and run in the hole to 3162.0 m (10 374 ft) as shown in Fig. 15.

The float shoe, float collar, and cementing stage collar (DV tool) had received black-light end-area and full-dimensional inspections. All of the 24.4-cm (9-5/8-in.) casing used in the string received Amalog IV (AMF Tuboscope), special end-area and full-length drifting inspections and were tallied and length checked three times independently. The Vallouvec VAM connections were torqued together at 18 400 ± 2000 N•m (13 500 ± 1500 ft•lb_f) and all buttress thread connections were torqued to midway up the triangle mark or to 1225 N•m (9000 ft•lb_f) maximum torque.

The only problem encountered was while running casing joint number 262 when the casing string lost weight. An attempt to lift the casing string was made; 2 x 10^6N (450 000 lb_f) pull by the drawworks only accomplished a stretch of the casing by 1.0 m (3.5 ft). The casing string appeared to be resting on some type of obstruction. A cementing head was attached to the top of the casing string and, using the rig pumps, the string was easily washed through the obstruction. The remaining joints of the string were run in without any problems. All available 24.4-cm (9-5/8-in.) casing was run.

Once the casing was run in, a stretch test on the casing string was conducted. An initial 1.70 x 10^6N (379 x 10^3 lb_f) load (that was equal to the net string weight less hole friction being supported) on the rig's drawworks was increased to 1.93 x 10^6N (434 000 lb_f) and resulted in only a 26.7-cm (10.5-in.) movement of the casing out of the hole. A 2.22 x 10^6N (500 000 lb_f) pull resulted in a total casing movement of 60.9 cm (24 in.). When the pull force was lowered back to 1.70 x 10^6N (380 000 lb_f) the casing moved back down hole 71.1 cm (28-in.), 10.2 cm (4-in.) further into the hole than before the stretch test was started.

5. Casing Cementing. After rigging down the casing-running hardware, a cementing head was installed and a 127 m^3 (801 bbls) clear-water preflush was pumped down the casing. The preflush was fresh water with a pH of 12.0. The preflush was followed by 3 m^3 (19 bbls) of a fresh water spacer with a pH of 7.0 mixed with 1.2% D-28 cement retarder. Next, 13 m^3 (84 bbls) of 1258 kg/m^3 (10.5 ppg) pozzolan scavenger cement slurry was mixed and pumped down the casing. The pozzolan cement slurry consisted of 288 sacks of pozzolan cement, 8.9 m^3 (56 bbls) of fresh water and 1.2% D-28 retarder.

Then the first stage cementing was performed by pumping 90.8 m^3 (200 bbls) of a 1992 kg/m^3 (16.6 ppg) cement slurry. This slurry had been premixed during the preceding 4-3/4 h. This first-stage-cement slurry formulation consisted of 950 sacks of class H cement, 22.9 m^3 (144 bbls) of fresh water, 40% silica flour, 40% 100 mesh silica sand, 2% bentonite, 0.75% D-65 turbulence enhancer, 0.6% L-10 and 1.2% D-28 retarders. This volume of cement, 90.8 m^3 (50 bbls), had been calculated to be 25% in excess of that needed to fill the annulus between the cement-plug shoe and the DV tool.

The wiper plug was then released from the cementing head and immediately followed with 111.6 m^3 (702 bbls) of displacement water. The first 1.6 m^3 (10 bbls) of the displacement water was fresh, had a pH of 7, and contained 1.2% D-28 cement retarder mixed in. The balance of the displacement water was fresh water with a pH of 12.0. The calculated displacement volume needed to displace all the cement to the float collar was 119.3 m^3 (750 bbls). However, the system pressured up to 22.8 MPa (3300 psi) at a volume 7.6 m^3 (48 bbls) short of the desired displacement. The casing pressure was released and approximately 1.6 m^3 (10 bbls) of water flowed back out of the casing. The flow stopped, indicating that the float was holding. An estimated 6.4 m^3 (40 bbls) of cement apparently remained in the bottom 200 m (650 ft) of casing.

The stage-collar-opening bomb was dropped and 40 min later the stage collar (DV tool) was opened by a surface pressure of 8.3 MPa (1200 psi) and pumping 0.3 m^3 (2 bbls) of pH 12.0 fresh water down the casing. After the stage collar opened an additional 3 m^3 (20 bbls) of pH 12.0 fresh water was pumped down the casing. Circulation through the stage collar then began using the rig pump and continued until cement was detected in returns. Circulation continued further until the returns became clear. Approximately 25 h after the completion of circulation through the stage collar a temperature survey was run. The tool was run down inside the casing to a (wireline) depth of 2219.6 m (7282 ft), confirming the location of the stage collar bomb blocking the casing i.d. The tool was then pulled up the casing to 2217.4 m (7275 ft) where a dwell for 2 h measured temperature and recovery rate of 138°C (280°F) and 0.1°C/h (0.05°F/h), respectively.

After waiting 72 h for the first-stage cement to set, the second stage and casing tensioning operations were begun. The casing slips and slips-restraining fixture were installed in the casing head. Next the hydraulic jack power-fluid piping system and casing tensioning jacks were tested (see Fig. 18). After testing, the jacks were cycled up and down five times to

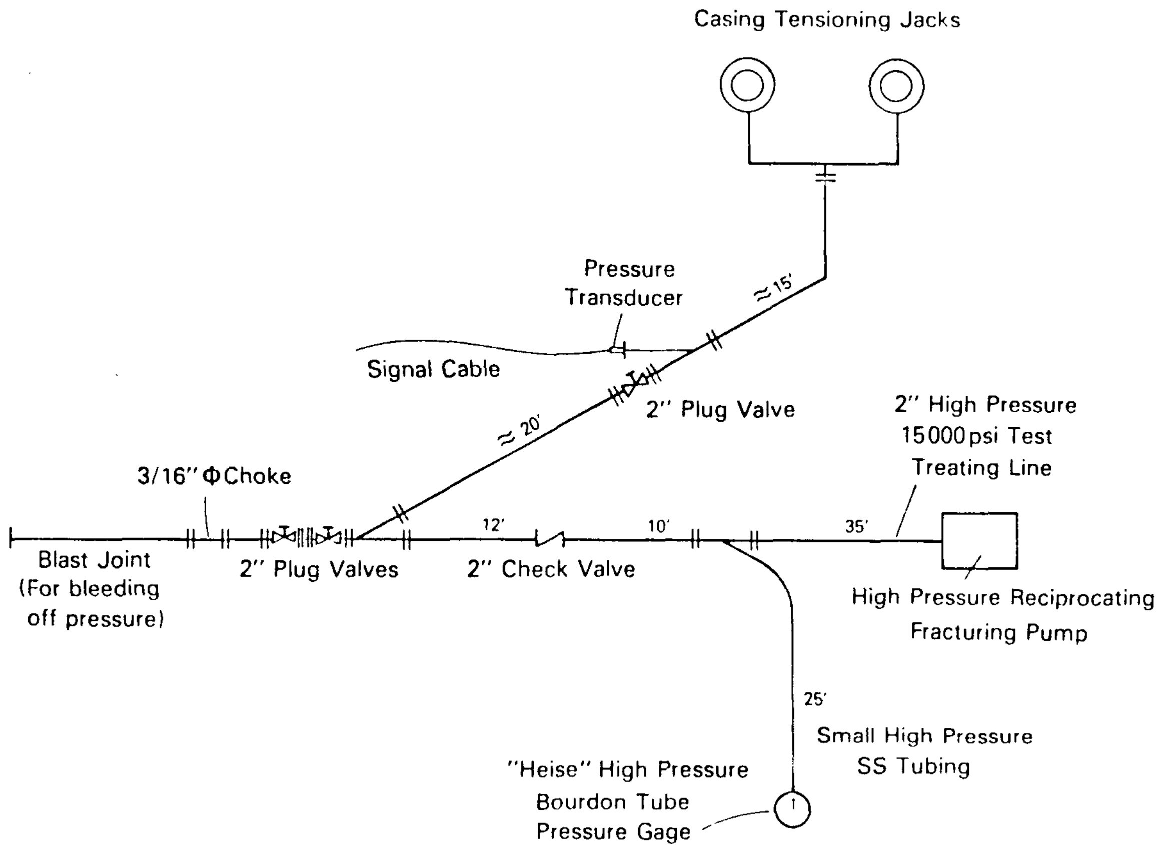

Fig. 18.
Schematic diagram of casing-jack power-fluid piping system.

stretch the casing and work tension down the casing. These cycles resulted in the following casing stretch.

Cycle No.	Casing Stretch, m (ft)	Jack Load, N (lb_f)
1	0.68 (2.25)	2.40×10^6 (539,000)
2	0.57 (1.9)	2.22×10^6 (498,600)
3	0.57 (1.9)	2.21×10^6 (496,700)
4	1.24 (4.1)	2.86×10^6 (643,000)
5	1.24 (4.1)	2.84×10^3 (639,100)

Upon the completion of cycling, the pressure on the jacks was released and the full casing load was placed on the jack cross head with cylinders in retracked position. Tension resulting from the jack cycling was worked down to approximately 1963 m (6440 ft) and 0.91 m (3.0 ft) of casing stretch was retained. The casing slips were then set in the casing head.

The second-stage cementing was preceded by the pumping of a 3 m^3 (20 bbls), pH 12.0, fresh-water preflush. The preflush was followed by a 3 m^3 (20 bbls) pH 7.0 fresh-water spacer containing 2% D-28 retarder. Next 52.5 m^3 (383 bbls) of a 1665 kg/m^3 (14 ppg) class H, perlite-lightened cement slurry was mixed and pumped down the casing; 30 m^3 (50 bbls) were premixed. The class H perlite slurry consisted of 1200 sacks of class H cement, 30.4 m^3 (191 bbls) of fresh water premixed with 2% D-28 retarder, 34 m^3 (1200 ft^3) of expanded perlite, 20% silica flour, 20% 100 mesh silica sand, 0.75% D65 turbulence enhancer, 2% bentonite and 0.2% D-46 anti-foam agent.

The rubber top wiper plug was then released and displaced by 82.2 m^3 (517 bbls) of pH 11 to 12 fresh water. A pressure of 21.4 MPa (3100 psi) displacement indicated that the plug had reached the stage collar. The calculated displacement volume was 84.7 m^3 (533 bbls). Surface pressure was released and 0.7 m^3 (5 bbls) of displacement water flowed back, but the flow ceased, indicating that the stage collar had closed.

The casing-tensioning jacks were then activated with 72.3 MPa (10 500 psi) and only negligible movement 0.6 cm (1/4-in.) of the casing occurred. Only one jack cylinder had moved and the jacks appeared to be binding. The problem was solved by releasing pressure on the jacks and centering the casing by pushing the casing slips down into the casing spool. Then the casing running slips on the rig were set and the rig line and drawworks were used to pull 2.11 x 10^6N (475 000 lb_f) on the casing while repressurizing the jacks. This procedure unbound the jacks and the jacks and casing began moving up. Chocks were placed between the casing landing spool and the casing slips restraining fixture, and the rig line and rig floor slips were slacked off and released.

The jacks were cycled up and down three times resulting in the casing being stretched an additional 1.55 m (5.1 ft) for a total [including 0.91 m (3.0 ft) of pre-second stage cementing casing stretch] of 2.47 m (8.1 ft). A pressure of 79.2 MPa (11 500 psi) was applied to the jacks and resulted in a final tensioning force of 4.02 x 10^6N (885 000 lb_f) that produced a 1.55 m (5.1 ft) increment of casing stretch. The chocks were pulled out and the casing slips were set in the casing landing spool. The jacks were lowered and only 0.03 m (0.1 ft) of casing stretch was lost.

The casing run-in and cementing procedures and operations occupied 13 days. The cement was allowed to set for 72 h, the cement was drilled out without incident on day 458 and the drill pipe was laid down. A Schlumberger cement bond log (CBL) was run on day 459. Review of the CBL has indicated that the logging tool had been improperly centralized and therefore the CBL results are unreliable. The density and neutron logs show possible weak bonding from 3073 to 3138 m (10 082 to 10 296 ft) with good bonding elsewhere. A second CBL has been recommended before fracturing operations are initiated.

VII. COST COMPARISONS

The drilled depth of well EE-3 (and EE-2) is unique in the development of high-grade U.S. geothermal resources. The majority of available drilling and cost data are for drilled depths of 3 km (10 000 ft) or less. The majority of such data are for hydrothermal development drilling and represent a data and experience base of less than 100 wells drilled in the U.S. per year[21] with total footage averaging about 180 km (500 000 ft) per year and for an average depth of about 2.2 km (7200 ft). Because five HDR wells have now been drilled at Fenton Hill, it is possible to compare these wildcat well costs to the experience with hydrothermal drilling costs and to project a "trouble-free" HDR drilling costs and to project a "trouble-free" HDR drilling cost trend for Fenton Hill conditions.

As another point of reference, about 2500 geothermal wells have been drilled worldwide and currently produce 2500 MW(e) of electricity from 163 high-grade hydrothermal fields.

A. Comparison With Hydrothermal Drilling Costs

A recent summary by Carson and Lin[22] is presented in Fig. 19, where the total drilling cost in 1979 dollars is plotted on a logarithmic scale vs well depth. These are the total costs paid to the drilling contractor. The average cost trend for drilling U.S. onshore oil and gas wells is plotted fór reference and is noted to be an exponential function of depth. The hydrothermal drilling costs range from about 2 to 4 times those for average oil and gas wells at a comparable depth. The reasons for these increased costs are due to the high temperatures, lost-circulation conditions, and hard rocks encountered in most hydrothermal reservoir areas. The trend noted for the Imperial Valley drilling costs reflect mostly the influences of higher temperatures because the subsurface formations are a sedimentary (sandstone-shale)

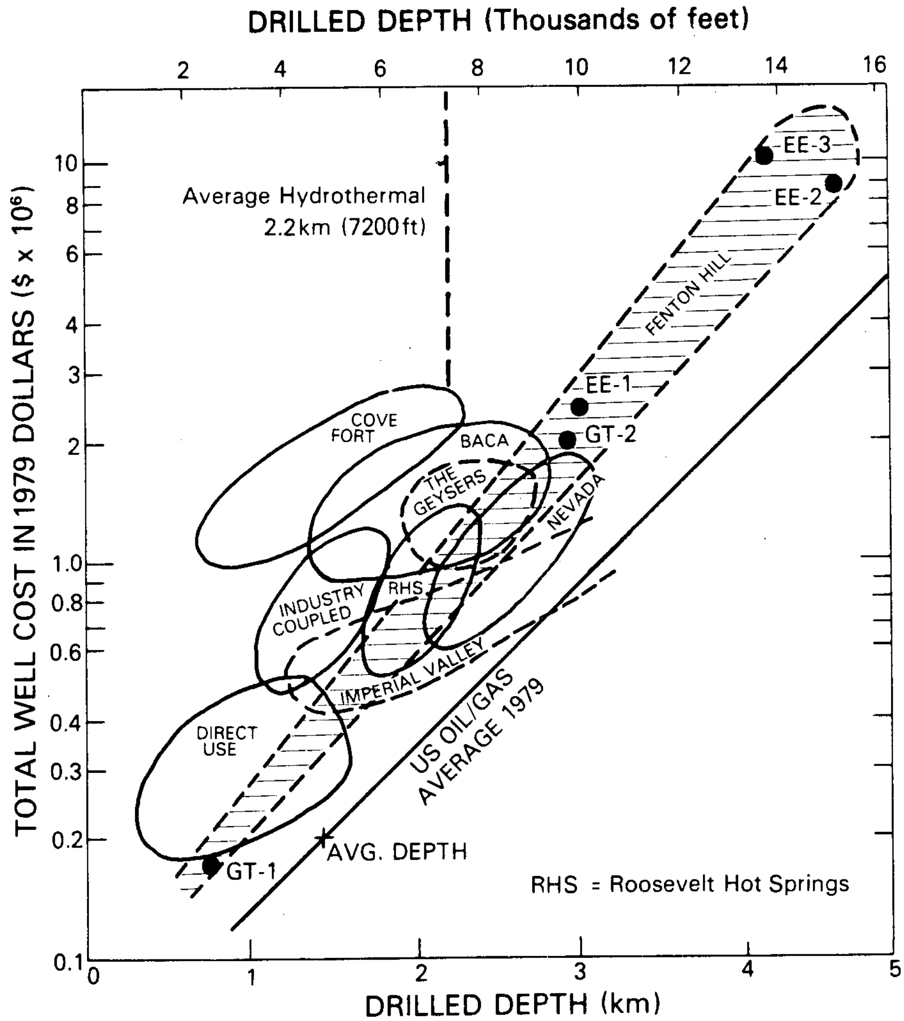

Fig. 19.
Comparison of commercial hydrothermal-well and Fenton Hill drilling costs.

stratigraphic sequence more closely related to the rocks and conditions encountered in oil and gas well drilling. The costs for HDR drilling at Fenton Hill are plotted on Fig. 19, adjusted to 1979 dollars, using the 17% per year escalation factor of Carson and Lin. The large spread noted for the hydrothermal drilling costs reflect the often wildcat nature of this type of drilling and compounding of problems due to high temperatures; i.e., problem solving procedures and techniques are adversely affected by elevated temperatures.

Figure 20 is a plot of drilling costs for U.S. DOE supported hydrothermal wells that was adapted from Ref. 23, and on the same scales, format and basis

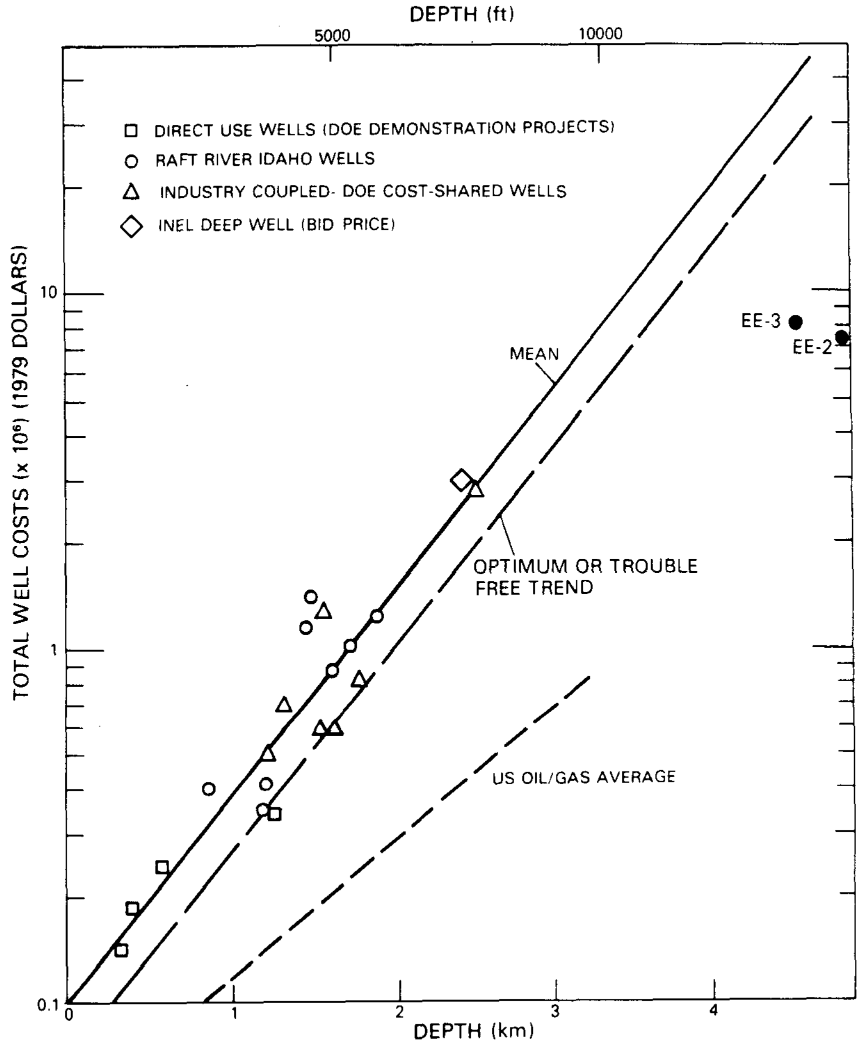

Fig. 20.
Comparison of DOE-sponsored hydrothermal-well to Fenton Hill drilling costs.

as Fig. 19. Again the authors have adjusted costs to 1973 dollars and projected an optimum or trouble-free drilling cost trend. The EE-2 and EE-3 costs are included for comparison with the extrapolated depth trends.

B. Estimation of Trouble-free Fenton Hill Drilling Costs

It is common practice in most drilling situations to attempt to project drilling costs after the experience of the first few wells in a reservoir area has been established. The costs of major problems and experiments conducted in the four deep HDR wells at Fenton Hill were available and can be removed from the total drilling costs. This was done[24] and the results are tabulated in Table XII. In this tabulation the Fenton Hill drilling costs were escalated to 1981 by the 17% annual rate suggested by Carson and Lin. In reviewing the costs for EE-3 it should be recognized that the drilling costs include directional drilling with precise inclination control and the directional drilling corrections in the deepest, hottest portion of the well required to keep the wellbore trajectory close to the N70°E vertical plane. The raw-cost-data ratio in Table XII shows that EE-3 cost about 3.1 times a comparable-depth oil and gas well. The projection to a trouble-free well cost reduces this ratio to 1.9. The trouble-free cost projection for EE-3 eliminated only the costs of solving the major fishing and sidetracking problems. Any improvements that might be expected to reduce problems associated with the 54 (compared to 30 for EE-2) directional drilling runs were not included in the cost reduction for EE-3. These additional directional runs account for the major part of the difference noted between EE-2 and EE-3 in the last column of Table XII, i.e., a ratio of 1.3 for EE-2 and 1.9 for EE-3 to oil and gas well drilling costs at comparable depths.

As a note of caution, it should be made clear that direct extension of Fenton Hill drilling costs to other areas should not be attempted. Overburden formations, crystalline rock, and temperature differences could bias costs significantly, especially for a first, or wildcat, well in a new area.

VIII. CONCLUSIONS

The controlled trajectory drilling of HDR well EE-3 was accomplished within very close dimensional tolerances as specified with respect to well EE-2. The vertical spacing of the inclined portion is 370 ± 30 m (1200 ± 50 ft) and the lateral location was maintained directly above EE-2 to within ± 30 m (± 100 ft), except for the bottommost section that drifted north slightly to about a 55 m (180 ft) offset from the EE-2 trajectory.

A large number of drilling problems were solved during the drilling operations. Drill pipe and BHA failures were the most serious. One twist-off required an extensive fishing procedure that failed to retrieve 43 m (140 ft) of the BHA. This, in turn, necessitated a sidetracking operation that proved to be very lengthy. This major problem occupied nearly 50% of the total drilling time. Close monitoring, and prevention of, crooked-hole conditions, improved high-temperature lubricity additives, strict drill-pipe inspection procedures, and improvements in some fishing tools (e.g. high-temperature wirelines and detonators for back-off shots) should minimize the impact of such problems in future HDR drilling programs. The completion of the drilling

TABLE XII

FENTON HILL HDR DRILLING COST COMPARISONS[a] TO AVERAGE OIL & GAS DRILLING COSTS

Fenton Hill HDR Well	Date Completed	Total Depth[b] km (ft)	Cost, 10^6\$, at Date Completed	Cost, 10^6\$ Escalated[c] to 1981	Oil & Gas Avg,[d] 10^6\$, Escalated to 1981	Ratio, 1981 Well Costs to Oil & Gas Avg.	Trouble Free 1981 Well Costs 10^6\$, with HDR Experiments & Major Problems Removed, Costs	Ratio 1981 HDR Well Costs with Major Problems & Exps. Removed, to Oil & Gas Avg
GT-2	10/1974	2.93 (9620)	1.9	5.2	1.1	5.2	3.3	3.0
EE-1	10/1975	3.06 (10,050)	2.3	5.9	1.3	4.5	3.2	2.4
EE-2	5/1980	4.66 (15,290)	7.3	8.5	4.9	1.7	6.3	1.3
EE-3	8/1981	4.25 (13,930)	11.5	11.5	3.7	3.1	6.9	1.9

[a] Adapted from the analysis of Ref. 24.
[b] Measured depth.
[c] Using a 17% per year, per Ref. 22.
[d] Oil & Gas Avg. Costs, extrapolated to 4.5 km and escalated at 17% per year.

of EE-3 provides an open-hole reservoir rock volume of 1.0 km (3000 ft) along the wellbore and nearly 580 m (1900 ft) horizontal in which to space the vertical fractures of the heat transfer/extraction system.

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However, specific references to a company, product name, service, tool, or equipment item does not imply approval or recommendation of the product, service or hardware by the University of California (Los Alamos National Laboratory) or the U.S. Department of Energy, to the exclusion of others that may be suitable.

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APPENDIX A

DAILY DRILLING LOG FOR EE-3

Abbreviations used:

BHA	bottom-hole assembly	LCM	lost-circulation material
BOP	blow-out preventer	POH	pull out of hole
CBL	cement bond log	Sii	Smith International, Inc.
DC	drill collar	SLM	strapped linear measurement
DV tool	cementing stage valve	TD	total depth
HWDP	Hevi-Wate drill pipe	TIH	trip into hole
KB	Kelly Bushing	WOC	waiting on cement
KOP	kick-off point		

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
1	5/22/80	141	26	141	Spudded EE-3, drilling ahead no problems, 26-in. hole.
2	5/23/80	480	26	339	Drilling ahead, 26-in. hole.
3	5/24/80	642	26	162	Circulation lost while drilling at 540 ft. Mixed LCM to regain circulation.
4	5/25/80	865	26	223	Partial circulation loss at 830 ft, Quick-Seal Pill alleviated problem.
5	5/26/80	989	26	124	Drilling ahead, changed to Bit No. 2 (button type).
6	5/27/80	1158	26	169	Drilling ahead, changed to toothed bit, Bit No. 3.
7	5/28/80	1348	26	190	Drilling ahead, 1-1/2° off vertical.
8	5/29/80	1559	26	211	Drilling ahead, penetrated Madera formation.
9	5/30/80	1696	26	137	Drilling ahead, rerun Bit No. 2 (button bit).

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
10	5/31/80	1872	26	176	Drilling ahead, hole conditions stable.
11	6/1/80	1923	26	51	Lost circulation, drilled into cavern, hit bridge at 480 ft. Regained returns while washing to bottom.
12	6/2/80	1923	26	0	Drilled through bridge and reopened hole, to 505 ft., severe obstruction.
13	6/3/80	1923	26	0	Lost returns at 1894 ft while reaming to bottom. Set cement plug at TD (500 sacks).
14	6/4/80	1923	26	0	Plug not successful, hit bridge at 458 ft, washed and reamed to TD.
15	6/5/80	1472	26	-451	Washed and reamed to 1792 ft, set second plug (500 sacks of cement).
16	6/6/80	1472	26	0	Hit bridge at 439 ft, washed to 459 ft without returns. Ran drill pipe to 1492 ft. Ran temperature log. Regained partial returns.
17	6/7/80	1775	26	303	Corrected unstable hole and drilled cement to 1775 ft.
18	6/8/80	1775	26	0	Waiting on casing crews and circulating, hole conditions stable.
		Set 20-in. Casing at 1580-ft KB			
19	6/9/80	1710	26	-65	Ran 20-in. casing to 1580 ft, preparing to cement. SLM 1710 ft.
20	6/10/80	1710	26	0	Cemented 20-in. casing with 2400 sacks through shoe, 500 sacks down annulus.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
21	6/11/80	1710	20	0	Put 150 additional sacks of cement into annulus (3050 sacks total).
22	6/12/80	1989	17-1/2	279	Drilled cement and shoe to 1860 ft, lost circulation, drilled to TD without circulation.
23	6/13/80	1989	17-1/2	0	Attempted to cement leak, 2500 sacks of cement pumped down.
24	6/14/80	2141	17-1/2	152	Drilled cement from 1825 ft to 1930 ft, lost circulation, no cement from 1930 ft to 1989 ft.
25	6/15/80	2298	17-1/2	157	Drilled to TD without returns, depleted on-site water.
26	6/16/80	2298	17-1/2	0	No drilling, waiting on water.
27	6/17/80	2407	17-1/2	109	Drilled to TD without returns, tag granite at 2404 ft.
28	6/18/80	2407	17-1/2	0	No drilling, waiting on water.
29	6/19/80	2538	17-1/2	131	Drilling ahead without returns.
		Set 13-3/8-in. Casing at 2552-ft KB			
30	6/20/80	2566	17-1/2	28	Drilled to TD, conditioned hole for 13-3/8-in. casing.
31	6/21/80	2566	17-1/2	0	Ran casing to 2552 ft, cemented casing into granite (200 sacks).
32	6/22/80	2566	17-1/2	0	Waiting on cement.
33	6/23/80	2566	17-1/2	0	Waiting on casing jacks.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
34	6/24/80	2566	17-1/2	0	Waiting on casing jacks.
35	6/25/80	2566	17-1/2	0	Waiting on casing jacks.
36	6/26/80	2566	17-1/2	0	Waiting on casing jacks.
37	6/27/80	2566	17-1/2	0	Waiting on 13-3/8-in. casing slips, jacks finally on hand.
38	6/28/80	2566	17-1/2	0	Casing was tensioned to 725 000 lb_f and 1000 sacks cement pumped through DV tool.
39	6/29/80	2566	12-1/4	0	Rigged BOP, drilled out shoe.
40	6/30/80	2640	12-1/4	74	Drilling ahead in pink granite.
41	7/1/80	2882	12-1/4	242	Drilling ahead, 1-1/2° off vertical.
42	7/2/80	3032	12-1/4	150	Drilling ahead, 10 ft/h.
43	7/3/80	3237	12-1/4	205	Drilling ahead.
44	7/4/80	3445	12-1/4	208	Drilling ahead.
45	7/5/80	3538	12-1/4	93	Drilling ahead, 2-1/4° off vertical.
46	7/6/80	3666	12-1/4	128	Drilling ahead, broke slickline, hole trending northwest.
47	7/7/80	3734	12-1/4	68	Twisted off between 5th and 6th drill collar, fished out OK.
48	7/8/80	3779	12-1/4	45	Washed out in a monel, Bit No. 12, hole 3-1/4° off vertical.
49	7/9/80	3965	12-1/4	186	Drilling ahead, hole now 4-3/4° northwest.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
50	7/10/80	4079	12-1/4	114	Drilling ahead, washout in DC, in with Bit No. 14.
51	7/11/80	4298	12-1/4	219	Drilling ahead, hole 4-1/4° off vertical northwest.
52	7/12/80	4358	12-1/4	60	Pump pressure loss, could not find the washout. Inspect BHA.
53	7/13/80	4485	12-1/4	127	Found washout in HWDP, resumed drilling.
54	7/14/80	4610	12-1/4	125	Washout detected, removed three drill collars and discarded.
55	7/15/80	4760	12-1/4	150	Drilling ahead, hole 5° off vertical.
56	7/16/80	4890	12-1/4	130	Drilling ahead 7-8 ft/h.
57	7/17/80	5120	12-1/4	230	Drilling ahead.
58	7/18/80	5248	12-1/4	128	Washout detected, hole 6° off vertical.
59	7/19/80	5420	12-1/4	172	Another washout, replaced all 6-3/4-in. DC with 8-in.
60	7/20/80	5538	12-1/4	118	Another washout in 8-in. DC and HWDP, hole is 7° off vertical toward northwest.
61	7/21/80	5737	12-1/4	199	Drilling ahead at 14.5 ft/h.
62	7/22/80	6205	12-1/4	468	Drilling ahead in white feldspar and biotite at 24 ft/h.
63	7/23/80	6334	12-1/4	129	Drilling ahead, gyro survey, hole 8-9° northwest at bottom.
64	7/24/80	6444	12-1/4	110	Twist off, drill collar failure, recovered OK.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
65	7/25/80	6444	12-1/4	0	KOP, preparation for directional run to turn hole to northeast.
66	7/26/80	6512	12-1/4	68	Motor run, drilling slowly as motor stalls easily.
67	7/27/80	6618	12-1/4	106	Motor run, drilling slowly, trouble orienting tool face.
68	7/28/80	6668	12-1/4	50	Can't orient downhole motor with single shot, reamed from 6440 ft to 6649 ft, angle 14° off vertical.
69	7/29/80	6710	12-1/4	42	Motor run, waiting on Scientific Drilling's "EYE" tool.
70	7/30/80	6710	12-1/4	0	Motor run, waiting on EYE tool.
71	7/31/80	6764	12-1/4	54	Motor run with EYE tool, 5 ft/h.
72	8/1/80	6809	12-1/4	45	Motor run with Dyna-Drill, hole is turning toward northeast.
73	8/2/80	6903	12-1/4	94	Motor run, reaming, and rotary drilling.
74	8/3/80	7017	12-1/4	114	Motor run, hole turned to N4°E.
75	8/4/80	7114	12-1/4	97	Motor run.
76	8/5/80	7179	12-1/4	65	Reamed to bottom and rotary drilled to TD.
77	8/6/80	7269	12-1/4	90	Motor run, Baker motor, 5-10 ft/h.
78	8/7/80	7269	12-1/4	0	Motor damaged while TIH, waiting on new motors.

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
79	8/8/80	7334	12-1/4	65	Motor run, Navidrill, same difficulty getting to TD.
80	8/9/80	7337	12-1/4	3	Bit damaged and washout, run magnet to check for junk. Some small pieces.
81	8/10/80	7427	12-1/4	90	Motor run.
82	8/11/80	7482	12-1/4	55	Motor run, end of directional drilling.
83	8/12/80	7542	12-1/4	60	Ream and rotary drill.
84	8/13/80	7542	12-1/4	0	Lay down drillpipe for inspection. Repair drawworks and inspect pipe.
85	8/14/80	7542	12-1/4	0	No drilling, repair drawworks and inspect pipe.
86	8/15/80	7542	12-1/4	0	No drilling, repair drawworks and inspect pipe.
87	8/16/80	7542	12-1/4	0	No drilling, repair drawworks and inspect pipe.
88	8/17/80	7542	12-1/4	0	No drilling, repair drawworks and inspect pipe.
89	8/18/80	7542	12-1/4	0	No drilling, repair drawworks.
90	8/19/80	7542	12-1/4	0	TIH to resume drilling.
91	8/20/80	7677	12-1/4	135	Drilling ahead.
92	8/21/80	7845	12-1/4	168	Drilling, prepare for directional run.
93	8/22/80	7845	12-1/4	0	Waiting on downhole motors.
94	8/23/80	7845	12-1/4	0	Attempted motor run, problem with EYE tool.
95	8/24/80	7856	12-1/4	11	Motor test, Sii turbine, problem with EYE tool.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
96	8/25/80	7863	12-1/4	7	Reamed to bottom, problem with EYE tool.
97	8/26/80	7905	12-1/4	42	Motor run, intermittent problem with EYE tool.
98	8/27/80	7940	12-1/4	35	Motor run.
99	8/28/80	8052	12-1/4	112	Motor run, tight hole.
100	8/29/80	8061	12-1/4	9	Ream and motor run. High torque, having trouble orienting motor.
101	8/30/80	8067	12-1/4	6	Ream and rotary drill.
102	8/31/80	8159	12-1/4	92	Motor run, problem with orienting motor.
103	9/1/80	8230	12-1/4	71	Motor run, plugged motor.
104	9/2/80	8265	12-1/4	35	Motor run, problem with EYE tool.
105	9/3/80	8265	12-1/4	0	Ream and rig for rotary drilling.
106	9/4/80	8407	12-1/4	142	Drilling ahead, washout suspected.
107	9/5/80	8407	12-1/4	0	Sii turbine test, won't drill.
108	9/6/80	8453	12-1/4	46	Hit bridge at 7140 ft. Ream with Sii turbine 7140 to 7230 ft. Rotary drill.
109	9/7/80	8624	12-1/4	171	Drilling ahead.
110	9/8/80	8727	12-1/4	103	Drilling ahead.
111	9/9/80	8827	12-1/4	100	Twist off at DC, hooked fish. SLM 8827 ft KB.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
112	9/10/80	8827	12-1/4	0	POH with fish, try Sandia Stratapax bit, o.d. too large for casing.
113	9/11/80	8925	12-1/4	98	Drilling ahead.
114	9/12/80	8942	12-1/4	17	Drilling ahead, laying down pipe for hard banding.
115	9/13/80	9113	12-1/4	171	Drilling ahead.
116	9/14/80	9190	12-1/4	77	Drilling ahead, change bit and ream to bottom.
117	9/15/80	9234	12-1/4	44	Drilling ahead, tight hole, stuck in hole 2 h.
118	9/16/80	9348	12-1/4	114	Reamed to bottom, drilling ahead.
119	9/17/80	9453	12-1/4	105	Drilling ahead.
120	9/18/80	9547	12-1/4	94	Drilling ahead.
121	9/19/80	9662	12-1/4	115	Drilling ahead.
122	9/20/80	9728	12-1/4	66	Drilling ahead.
123	9/21/80	9822	12-1/4	94	Drilling ahead, called out directional drilling.
124	9/22/80	9850	12-1/4	28	Drilling ahead, rig for motor run.
125	9/23/80	9879	12-1/4	29	Motor run, problem with motor.
126	9/24/80	9879	12-1/4	0	Fish slip handle from hole.
127	9/25/80	9924	12-1/4	45	Sloughing, possible leak in 13-3/8-in. casing.
128	9/26/80	9924	12-1/4	0	Leak stopped.
129	9/27/80	9987	12-1/4	63	Sloughing, soft formation at TD.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
130	9/28/80	9987	12-1/4	0	Waiting on turbines.
131	9/29/80	9987	12-1/4	0	Waiting on turbines, dredging reserve pit.
132	9/30/80	9987	12-1/4	0	Waiting on turbines.
133	10/1/80	9987	12-1/4	0	Waiting on turbines, lost circulation zone at TD.
134	10/2/80	10 017	12-1/4	30	Drilling, waiting on turbines, lost circulation zone at TD, ran LCM sweeps.
135	10/3/80	10 017	12-1/4	0	Ran bond log.
136	10/4/80	10 017	12-1/4	0	Attempted Sii Dyna-Drill turbine run, possible washout.
137	10/5/80	10 017	12-1/4	0	Waiting on Maurer turbines.
138	10/6/80	10 116	12-1/4	99	Turbine run.
139	10/7/80	10 116	12-1/4	0	Reamed directional hole.
140	10/8/80	10 123	12-1/4	7	Turbine run, motor locked up.
141	10/9/80	10 150	12-1/4	27	Turbine run, intermittent water losses.
142	10/10/80	10 261	12-1/4	111	Turbine run, hole now at 27° from vertical.
143	10/11/80	10 303	12-1/4	42	Drilling ahead, ream to bottom.
144	10/12/80	10 334	12-1/4	31	Turbine run, problem with EYE tool.
145	10/13/80	10 369	12-1/4	35	Reamed to TD, turbine run.
146	10/14/80	10 378	12-1/4	9	Turbine run, EYE tool stuck.
147	10/15/80	10 417	12-1/4	39	Turbine run, EYE tool repair.
148	10/16/80	10 417	12-1/4	0	Waiting on EYE tool repair.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
149	10/17/80	10 417	12-1/4	0	Reamed to TD, hole very tight.
150	10/18/80	10 417	12-1/4	0	Reaming, twist off at mid-string, fishing.
151	10/19/80	10 417	12-1/4	0	Part of lost string fished out.
152	10/20/80	10 417	12-1/4	0	Fishing, no luck.
153	10/21/80	10 417	12-1/4	0	Fishing, no luck.
154	10/22/80	10 417	12-1/4	0	Pulled out fish, reamed to TD.
155	10/23/80	10 417	12-1/4	0	Attempted turbine run, EYE tool problems.
156	10/24/80	10 463	12-1/4	46	Turbine run, new EYE tool.
157	10/25/80	10 463	12-1/4	0	Reamed to TD.
158	10/26/80	10 505	12-1/4	42	Turbine and rotary drilling.
159	10/27/80	10 528	12-1/4	23	Rotary drilling, problem with tight hole and turbo.
160	10/28/80	10 528	12-1/4	0	Reaming, twist off at 7070 ft, fishing.
161	10/29/80	10 528	12-1/4	0	Waiting on wireline and back-off tools.
162	10/30/80	10 528	12-1/4	0	Attempted backoff at 10 405 ft, no luck.
163	10/31/80	10 528	12-1/4	0	Back-off shot got 1/2 jar and some string.
164	11/1/80	10 528	12-1/4	0	Back-off shot got everything down to collars.
165	11/2/80	10 528	12-1/4	0	Pipe pulled in two. Kelly wedged in rotary table, broke, and was lost in hole.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
166	11/3/80	10 528	12-1/4	0	Rig up to try to back-off Kelley fish. Backed off and pulled 36 joints.
167	11/4/80	10 528	12-1/4	0	Jarring on upper fish, no good, three fish in hole.
168	11/5/80	10 528	12-1/4	0	Five joints of drill pipe backed off and out.
169	11/6/80	10 528	12-1/4	0	Fifteen and one half joints of drill pipe backed off and out.
170	11/7/80	10 528	12-1/4	0	Five joints of drill pipe backed off and out.
171	11/8/80	10 528	12-1/4	0	Jarring moved fish 8 ft. Jarred drill pipe in two below screw-in sub.
172	11/9/80	10 528	12-1/4	0	Seventeen foot piece of drill pipe fished out.
173	11/10/80	10 528	12-1/4	0	Lost jars and drill collars, fish No. 4. Accelerator parted.
174	11/11/80	10 528	12-1/4	0	Jarring. Run back-off shot.
175	11/12/80	10 528	12-1/4	0	Fish No. 4 pulled, fish No. 3 hooked and started out.
176	11/13/80	10 528	12-1/4	0	Removed fish No. 3, worked on No. 2.
177	11/14/80	10 528	12-1/4	0	Fishing, no luck, fish blocked on inside by piece of metal.
178	11/15/80	10 528	12-1/4	0	Fishing, waiting on washover and cutter tools.
179	11/16/80	10 528	12-1/4	0	Fishing, unsuccessful washover try. Using outside cutter.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
180	11/17/80	10 528	12-1/4	0	Fishing, cut and removed 1-1/2 joints drill pipe.
181	11/18/80	10 528	12-1/4	0	Backed off and pulled 1-1/2 joints.
182	11/19/80	10 528	12-1/4	0	Backed off at 9180 ft.
183	11/20/80	10 528	12-1/4	0	Pulled back off section, ran casing caliper.
184	11/21/80	10 528	12-1/4	0	Picked up 4-1/2-in. drill pipe.
185	11/22/80	10 528	12-1/4	0	Ran swage run into 13-3/8-in. casing. Picked up more 4-1/2-in. drill pipe.
186	11/23/80	10 528	12-1/4	0	Hooked fish at 9180 ft, could not pull.
187	11/24/80	10 528	12-1/4	0	Lost part of back-off tool. Back-off pipe at 9229.
188	11/25/80	10 528	12-1/4	0	Removed fish and back-off tool to 9229 ft, twisted off 3550 ft.
189	11/26/80	10 528	12-1/4	0	Backed off at 10 150 ft.
190	11/27/80	10 528	12-1/4	0	Tripped out fish.
191	11/28/80	10 528	12-1/4	0	Inspect and straighten pipe.
192	11/29/80	10 528	12-1/4	0	Pick up drill pipe.
193	11/30/80	10 528	12-1/4	0	Fishing at 10 180 ft.
194	12/1/80	10 528	12-1/4	0	Fishing at 10 180 ft, unsuccessful back-offs.
195	12/2/80	10 528	12-1/4	0	Fishing at 10 180 ft.
196	12/3/80	10 528	12-1/4	0	Pulled out all but 140 ft of fish.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
197	12/4/80	10 528	12-1/4	0	Inspecting pipe.
198	12/5/80	10 528	12-1/4	0	Inspecting pipe.
199	12/6/80	10 528	12-1/4	0	Fishing, moved fish up 5 ft.
200	12/7/80	10 528	12-1/4	0	Fishing.
201	12/8/80	10 528	12-1/4	0	Fishing at 10 338 ft, no luck.
202	12/9/80	10 528	12-1/4	0	Fishing at 10 338 ft, no luck.
203	12/10/80	10 528	12-1/4	0	Fishing at 10 338 ft, no luck.
204	12/11/80	10 528	12-1/4	0	Decision to sidetrack made.
205	12/12/80	10 528	12-1/4	0	Waiting on tools.
206	12/13/80	10 528	12-1/4	0	Waiting on tools.
207	12/14/80	10 528	12-1/4	0	Waiting on tools, rig to underream.
208	12/15/80	10 528	12-1/4	0	Underreaming, stuck tool.
209	12/16/80	10 528	12-1/4	0	Underreaming at 9760 ft, 14 ft cut.
210	12/17/80	10 528	12-1/4	0	Underreaming at 9885 ft, 15 ft cut.
211	12/18/80	9738	12-1/4	-790	Cemented hole, 500 sacks of Class H.
212	12/19/80	9738	12-1/4	0	Tagged cement, drill to 9770 ft in soft cement.
213	12/20/80	9770	12-1/4	32	Waiting on cement.
214	12/21/80	9188	12-1/4	-582	Cemented plug, 400 sacks of Class H.
215	12/22/80	9494	12-1/4	306	Drilling soft cement.
216	12/23/80	9786	12-1/4	292	Drilling soft cement, will not set.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
217	12/24/80	9950	12-1/4	164	Drilling soft cement.
218	12/25/80	9440	12-1/4	-510	Cemented plug, 300 sacks of Class H.
219	12/26/80	9635	12-1/4	195	Drilling soft cement, will not set.
220	12/27/80	9665	12-1/4	30	Drilling soft cement, ran temperature log.
221	12/28/80	9665	12-1/4	0	Waiting on cement.
222	12/29/80	9720	12-1/4	55	Drilling soft cement.
223	12/30/80	9998	12-1/4	278	Drill out soft cement plug.
224	12/31/80	9557	12-1/4	-441	Recement plug (fourth try), 400 sacks of Class H.
225	1/1/81	9557	12-1/4	0	Waiting on cement.
226	1/2/81	9653	12-1/4	96	Drilling soft cement.
227	1/3/81	9704	12-1/4	51	Drilling soft cement.
228	1/4/81	9721	12-1/4	17	Drilling soft cement.
229	1/5/81	10 100	12-1/4	379	Drilled out soft plug.
230	1/6/81	10 101	12-1/4	0	Set up to recement. SLM 10 101.
231	1/7/81	10 101	12-1/4	0	Set up to recement.
232	1/8/81	9428	12-1/4	-673	Fifth try at cementing, 450 sacks of Class H.
233	1/9/81	9498	12-1/4	70	Drilled into harder cement.
234	1/10/81	9550	12-1/4	52	Drilled into harder cement, not much harder.
235	1/11/81	9565	12-1/4	15	Coring into harder cement.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
236	1/12/81	9778	12-1/4	213	Drilling into medium hard cement.
237	1/13/81	9820	12-1/4	42	Drilling into medium hard cement.
238	1/14/81	9820	12-1/4	0	Temperature log and cooling.
239	1/15/81	9128	12-1/4	-692	Sixth try at cementing, 350 sacks of cement.
240	1/16/81	9175	12-1/4	47	Drilling soft cement.
241	1/17/81	9600	12-1/4	425	Drilling soft cement.
242	1/18/81	9619	12-1/4	19	Core out hard cement.
243	1/19/81	9724	12-1/4	105	Rig up to directional drill a sidetrack.
244	1/20/81	9724	9-7/8	0	Rig up to directional drill a sidetrack.
245	1/21/81	9724	9-7/8	0	Clear obstruction in string.
246	1/22/81	9767	9-7/8	43	Attempt to sidetrack.
247	1/23/81	9780	9-7/8	13	Attempt to sidetrack, not successful.
248	1/24/81	9800	12-1/4	20	Try to set Whipstock, hit tight spot.
249	1/25/81	9800	12-1/4	0	Ream from 6855 to 6978 ft.
250	1/26/81	9800	12-1/4	0	Ream to 7387.
251	1/27/81	9800	12-1/4	0	Attempt to set whipstock, no go.
252	1/28/81	9800	12-1/4	0	Readied to recement and directional drill.
253	1/29/81	9379	12-1/4	-421	Cemented plug, 230 sacks of cement.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
254	1/30/81	9409	12-1/4	30	Drilled off top of soft cement.
255	1/31/81	9500	12-1/4	91	Drilled out soft cement.
256	2/1/81	9500	12-1/4	0	Underreamed 21 ft, 9293 ft to 9314 ft, 16-in. diam.
257	2/2/81	9500	12-1/4	0	Underreamed to 9314 ft to 9330 ft, 16-in. diam.
258	2/3/81	9175	12-1/4	-325	Cement Plug No. 8, 300 sacks of Class J.
259	2/4/81	9195	12-1/4	20	Dress off cement plug.
260	2/5/81	9158	12-1/4	0	Core run on top of cement, looks hard. SLM 9158 ft.
261	2/6/81	9250	12-1/4	92	Core and facing off cement.
262	2/7/81	9300	8-3/4	50	Dress off cement plug.
263	2/8/81	9300	8-3/4	0	Attempted sidetrack with motor.
264	2/9/81	9300	8-3/4	0	Attempted sidetrack with motor.
265	2/10/81	9304	8-3/4	4	Attempted sidetrack with motor.
266	2/11/81	9319	8-3/4	15	Attempted sidetrack with motor.
267	2/12/81	9323	8-3/4	4	Attempted sidetrack with motor.
268	2/13/81	9323	8-3/4	0	Attempted sidetrack with motor. Magnet run.
269	2/14/81	9323	8-3/4	0	Magnet run, no junk.
270	2/15/81	9325	8-3/4	2	Attempted sidetrack with motor; toothed bit run with junk basket for clean up.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
271	2/16/81	9329	8-3/4	4	Attempted sidetrack.
272	2/17/81	9339	8-3/4	10	Attempted sidetrack, some granite cuttings.
273	2/18/81	9382	8-3/4	43	Attempted sidetrack, fished out cones.
274	2/19/81	9386	8-3/4	4	Attempted sidetrack, EYE tool problems.
275	2/20/81	9397	8-3/4	11	Attempted sidetrack.
276	2/21/81	9416	8-3/4	19	Attempted sidetrack.
277	2/22/81	9416	12-1/4	0	Opened hole up to 12-1/4 in.
278	2/23/81	9416	12-1/4	0	Opened hole up to 12-1/4 in.
279	2/24/81	9497	12-1/4	81	Opened hole up to 12-1/4 in.
280	2/25/81	9501	12-1/4	4	Opening up hole, run single shot surveys.
281	2/26/81	9501	12-1/4	0	Cooled hole for whipstock installation.
282	2/27/81	9501	12-1/4	0	Cooled hole for whipstock installation.
283	2/28/81	9501	12-1/4	0	Cooled hole for whipstock installation.
284	3/1/81	9501	12-1/4	0	Whipstock on bottom, problem orienting.
285	3/2/81	9173	12-1/4	-328	Whipstock oriented and cemented with 185 sacks.
286	3/3/81	9173	12-1/4	0	Waiting on cement. Run bond log on 13-3/8-in. casing.
287	3/4/81	9173	12-1/4	0	Running wall thickness log, 13-3/8-in. casing.

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
288	3/5/81	9173	12-1/4	0	Hardband drill pipe.
289	3/6/81	9263	12-1/4	90	Hit bridge @ 6838 ft while tripping in hole. Drilling cement.
290	3/7/81	9277	12-1/4	14	Coring and facing off cement.
291	3/8/81	9325	12-1/4	48	Facing off cement and attempted sidetrack.
292	3/9/81	9396	12-1/4	71	Motor run, attempt to sidetrack.
293	3/10/81	9432	12-1/4	36	Rotary drill to whipstock.
294	3/11/81	9435	12-1/4	3	Drill on junk.
295	3/12/81	9439	12-1/4	4	Drill on junk.
296	3/13/81	9439	12-1/4	0	Five junk runs, metal scrap in basket.
297	3/14/81	9440	12-1/4	1	Junk and magnet runs, something in hole. Milling.
298	3/15/81	9443	12-1/4	3	Milling run on whipstock.
299	3/16/81	9443	12-1/4	0	Twisted off at DC, fishing.
300	3/17/81	9446	8-5/8	3	Pulled fish, milling on bottom of hole.
301	3/18/81	9451	8-5/8	5	Milling off whipstock.
302	3/19/81	9451	12-1/4	0	Open hole out to 12-1/4 in. with tapered mill and bit.
303	3/20/81	9451	12-1/4	0	Two magnet runs.
304	3/21/81	9461	12-1/4	10	Drilling off whipstock.
305	3/22/81	9558	12-1/4	97	EE-3 is sidetracked, drilling granite.
306	3/23/81	9558	12-1/4	0	Changed out BOP stack.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
307	3/24/81	9558	12-1/4	0	Reamed to bottom.
308	3/25/81	9558	12-1/4	0	Hole is sidetracked to east, magnet run.
309	3/26/81	9558	12-1/4	0	Attempted motor run, EYE trouble.
310	3/27/81	9631	12-1/4	73	Motor run.
311	3/28/81	9718	12-1/4	87	Reamed to bottom and drilled ahead.
312	3/29/81	9771	12-1/4	53	Motor run.
313	3/30/81	9843	12-1/4	72	Ream and drill ahead.
314	3/31/81	9883	12-1/4	40	Drill ahead and gyro survey, no good.
315	4/1/81	9883	12-1/4	0	Re-survey.
316	4/2/81	9883	12-1/4	0	Re-survey.
317	4/3/81	9884	12-1/4	1	Reamed to bottom.
318	4/4/81	9884	12-1/4	0	Attempt to gyro survey, no go.
319	4/5/81	9890	12-1/4	6	Drilling ahead, good survey.
320	4/6/81	10 037	12-1/4	147	Drilling ahead.
321	4/7/81	10 106	12-1/4	69	Drilling ahead.
322	4/8/81	10 170	12-1/4	64	Drilling ahead.
323	4/9/81	10 226	12-1/4	56	Drilling ahead, fixed washout, survey tool backed out.
324	4/10/81	10 226	12-1/4	0	Layed down drill pipe.
325	4/11/81	10 226	12-1/4	0	Pipe inspection and casing log, no problems.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
326	4/12/81	10 226	12-1/4	0	Hard banding and inspection operations.
327	4/13/81	10 226	12-1/4	0	Pipe inspection.
328	4/14/81	10 226	12-1/4	0	Pipe inspection completed.
329	4/15/81	10 226	12-1/4	0	Pick up pipe and run into hole.
330	4/16/81	10 226	12-1/4	0	Rig for motor run.
331	4/17/81	10 226	12-1/4	0	Turbine and EYE tool problems.
332	4/18/81	10 226	12-1/4	0	Turbine and EYE tool problems.
333	4/19/81	10 226	12-1/4	0	No turbine run, tool problems.
334	4/20/81	10 245	12-1/4	19	Turbine run, tool problems.
335	4/21/81	10 245	12-1/4	0	Reamed to TD.
336	4/22/81	10 352	12-1/4	107	Short turbine run.
337	4/23/81	10 352	12-1/4	0	Ream to TD, reaming hard.
338	4/24/81	10 352	12-1/4	0	Ream to TD, reaming hard.
339	4/25/81	10 400	12-1/4	48	Ream and drill ahead.
340	4/26/81	10 440	12-1/4	40	Turbine run.
341	4/27/81	10 512	12-1/4	72	Ream and drill ahead.
342	4/28/81	10 573	12-1/4	61	Ream and drill ahead.
343	4/29/81	10 573	12-1/4	0	Ream to TD.
344	4/30/81	10 633	12-1/4	60	Turbine run.
345	5/1/81	10 658	12-1/4	25	Turbine run and ream.
346	5/2/81	10 734	12-1/4	76	Ream and drill ahead.
347	5/3/81	10 734	12-1/4	0	Turbine problems.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
348	5/4/81	10 791	12-1/4	57	Turbine run.
349	5/5/81	10 811	9-7/8	20	Ream and drill ahead, change to 9-7/8-in. bit, 10 791 to 10 811 ft.
		Reduced Hole Diam Drilling Into Reservoir Section			
350	5/6/81	10 938	8-3/4	127	Drilling ahead, 8-3/4 in.bit.
351	5/7/81	11 120	8-3/4	182	Drilling ahead, lost slickwire in string.
352	5/8/81	11 120	8-3/4	0	Stuck in hole, keyseated, lost wireline, fishing.
353	5/9/81	11 120	8-3/4	0	Recovered wireline, string still stuck.
354	5/10/81	11 120	8-3/4	0	Jarred pipe loose.
355	5/11/81	11 156	8-3/4	36	Tripped 12-1/4 in. bit through stuck zone approx. 6500 ft. Encountered nothing. Drilling ahead.
356	5/12/81	11 359	8-3/4	203	Drilling ahead 12 ft/h.
357	5/13/81	11 454	8-3/4	95	Drilling ahead, some tight hole problems.
358	5/14/81	11 454	8-3/4	0	String layed down and exchanged for inspection.
359	5/15/81	11 595	8-3/4	141	Drilling ahead.
360	5/16/81	11 730	8-3/4	135	Drilling ahead.
361	5/17/81	11 913	8-3/4	183	Drilling ahead, some tight hole.
362	5/18/81	11 926	8-3/4	13	Ream and drill ahead, H_2S problem found.
363	5/19/81	11 926	8-3/4	0	Treating H_2S problem.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
364	5/20/81	11 951	8-3/4	25	Turbine run.
365	5/21/81	11 982	8-3/4	31	Ream and drill, string stuck temporarily.
366	5/22/81	12 059	8-3/4	77	Drilling ahead, excessive torque and drag.
367	5/23/81	12 079	8-3/4	20	Stuck pipe, jarred loose, high drag.
368	5/24/81	12 079	8-3/4	0	Washed with water which reduced drag.
369	5/25/81	12 079	8-3/4	0	Cleaning pits.
370	5/26/81	12 100	8-3/4	21	Drilling ahead with water and torque trim.
371	5/27/81	12 100	8-3/4	0	Waiting for heat shield for EYE tool.
372	5/28/81	12 186	8-3/4	86	Turbine run.
373	5/29/81	12 191	8-3/4	5	Ream to TD and drill.
374	5/30/81	12 191	8-3/4	0	Rig drum clutch repair.
375	5/31/81	12 310	8-3/4	119	Turbine run.
376	6/1/81	12 412	8-3/4	102	Ream to TD. Drilling ahead, up to 15 ft/h.
377	6/2/81	12 511	8-3/4	99	Drilling ahead.
378	6/3/81	12 576	8-3/4	65	Drilling. Picking up a lot of cuttings from ponds.
379	6/4/81	12 576	8-3/4	0	Cleaning ponds.
380	6/5/81	12 576	8-3/4	0	Cleaning ponds, H_2S problem.
381	6/6/81	12 576	8-3/4	0	Cleaning ponds, H_2S problem.
382	6/7/81	12 576	8-3/4	0	Cleaning ponds, H_2S problem.

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
383	6/8/81	12 609	8-3/4	33	Drilling ahead, hole is getting tight.
384	6/9/81	12 728	8-3/4	119	Drilling ahead, H_2S OK. Hole tight.
385	6/10/81	12 874	8-3/4	146	Drilling ahead at 12 ft/h.
386	6/11/81	12 895	8-3/4	21	Drilling ahead, bit change.
387	6/12/81	12 961	8-3/4	66	Turbine run. Hole tight.
388	6/13/81	12 961	8-3/4	0	Attempted turbine run.
389	6/14/81	12 961	8-3/4	0	Attempted turbine run.
390	6/15/81	13 117	8-3/4	156	Drilling ahead.
391	6/16/81	13 312	8-3/4	195	Drilling ahead.
392	6/17/81	13 365	8-3/4	53	Drilling ahead, lay down string.
393	6/18/81	13 365	8-3/4	0	Pick up new string, set up for motor run.
394	6/19/81	13 365	8-3/4	0	Attempted turbine run.
395	6/20/81	13 365	8-3/4	0	Tight hole. Run reaming assembly. Twist off at 6500 ft while reaming to bottom.
396	6/21/81	13 365	8-3/4	0	Fishing, jars in fish will not operate.
397	6/22/81	13 365	8-3/4	0	Fishing, rig to try back off.
398	6/23/81	13 365	8-3/4	0	Fishing, free point 13 200 ft.
399	6/24/81	13 365	8-3/4	0	Fishing, back off at 8358 ft.
400	6/25/81	13 365	8-3/4	0	Fishing, back off @ 8701 ft.
401	6/26/81	13 365	8-3/4	0	Fishing, perforate @ 12 216 and 12 915 ft to circulate and cool hole.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
402	6/27/81	13 365	8-3/4	0	Fishing, backed off at 12 195 ft.
403	6/28/81	13 365	8-3/4	0	Fishing, TIH with S-pipe and jar.
404	6/29/81	13 365	8-3/4	0	Fishing, 4 back-off shots.
405	6/30/81	13 365	8-3/4	0	Explosive cut off at 12 953 ft.
406	7/1/81	13 365	8-3/4	0	String keyseated at 6550 ft on way out.
407	7/2/81	13 365	8-3/4	0	Back off at 6483 ft, jarred free and POH.
408	7/3/81	13 365	8-3/4	0	Reaming keyseat at 6500 ft.
409	7/4/81	13 365	8-3/4	0	Attempted ream, hole tight near bottom.
410	7/5/81	13 365	8-3/4	0	Reaming tight hole.
411	7/6/81	13 365	8-3/4	0	Work tight hole.
412	7/7/81	13 365	8-3/4	0	Milled top of fish. Attempted hook on to fish, no go.
413	7/8/81	13 365	8-3/4	0	Hooked fish but fell off.
414	7/9/81	13 365	8-3/4	0	Hardbanding interferring with grappel. Milling off hardband.
415	7/10/81	13 365	8-3/4	0	Attempt to hook fish, no go.
416	7/11/81	13 365	8-3/4	0	Mill on fish. Hole tight.
417	7/12/81	13 365	8-3/4	0	String broke at old cut off spot, 1-1/2 joints in. Mill on 2nd shot point.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
418	7/13/81	13 365	8-3/4	0	Milling, twist off and back off, 5100 ft and 600 ft respectively.
419	7/14/81	13 365	8-3/4	0	Both fish pulled from hole H_2S up.
420	7/15/81	13 365	8-3/4	0	Circulated hole, treated H_2S problem.
421	7/16/81	13 365	8-3/4	0	Reaming keyseat at 6500 ft, inspecting string.
422	7/17/81	13 365	8-3/4	0	Reaming keyseat and milling on fish, inspecting string.
423	7/18/81	13 365	8-3/4	0	Milling on fish, inspecting string.
424	7/19/81	13 365	8-3/4	0	Finished inspecting string. Work overshot, no luck.
425	7/20/81	13 365	8-3/4	0	Hooked fish, moved up about 200 ft, overshot kept slipping off. Drilling jars working.
426	7/21/81	13 365	8-3/4	0	Grappel not holding, fish loose but still in hole. Run smaller grapple, fish coming out of hole.
427	7/22/81	13 365	8-3/4	0	Fish pulled from hole. Run magnet.
428	7/31/81	13 365	8-3/4	0	Magnet and junk basket run, recovered some junk.
429	7/24/81	13 365	8-3/4	0	Run bit, would not drill. Torquing on bottom.
430	7/25/81	13 365	8-3/4	0	Two magnet runs, recovered junk.

APPENDIX A (cont.)

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
431	7/26/81	13 365	8-3/4	0	Another magnet run. Drilled on junk and torqued up. Rig repairs.
432	7/27/81	13 365	8-3/4	0	Milled on junk. Rig repairs.
433	7/28/81	13 365	8-3/4	0	Two magnet and junk basket runs. Recovered large pieces of metal.
434	7/29/81	13 365	8-3/4	0	Magnet and junk basket run.
435	7/30/81	13 365	8-3/4	0	Two magnet and junk basket runs. Junk cleaning up.
436	7/31/81	13 338	8-3/4	0	Magnet and junk basket run. Drilled new hole with mill-toothed bit. Pipe strap corrected depth.
437	8/1/81	13 484	8-3/4	146	Normal drilling. Slightly high torque. One magnetic single shot survey.
438	8/2/81	13 494	8-3/4	10	Pulled drill string apart at 9683 ft. Fishing.
439	8/3/81	13 494	8-3/4	0	Recovered fish. Inspecting all tool joints on rig floor.
440	8/4/81	13 519	8-3/4	25	Resumed drilling. Tripped to change leaky jars.
441	8/5/81	13 701	8-3/4	182	Drilled ahead. High torque.
442	8/6/81	13 911	8-3/4	210	Drilled smoothly, using Torq-Trim. Three directional surveys.
443	8/7/81	13 933	8-3/4	22	Reached TD. Cleaning hole.
444	8/8/81	13 933	8-3/4	0	Cleaned and scraped hole. Displaced fluid with soap. Ran temperature survey.

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
445	8/9/81	13 933	8-3/4	0	Schlumberger attempted to run borehole geometry log. Dowell set retaining plug. WOC.
446	8/10/81	13 933	8-3/4	0	Dress cement plug. Plug not solid. Circulated to cool for logging.
447	8/11/81	13 933	8-3/4	0	Ran Los Alamos temperature survey and Schlumberger neutron density and gamma logs.
448	8/12/81	13 933	8-3/4	0	Recemented retainer plug with 270 sacks. WOC.
449	8/13/81	13 933	8-3/4	0	Faced off plug to 10 400 ft.
450	8/14/81	13 933	8-3/4	0	Set casing jacks and started running 9-5/8-in. casing. Set 9-5/8-in. casing @ 10 374 ft KB.
451	8/15/81	13 933	8-3/4	0	Landed 9-5/8-in. casing at 10 374 ft. Circulated 12 pH water.
452	8/16/81	13 933	8-3/4	0	Dowell cemented first stage with 950 sacks.
453	8/17/81	13 933	8-3/4	0	WOC. Ran Los Alamos temperature survey.
454	8/18/81	13 933	8-3/4	0	WOC.
455	8/19/81	13 933	8-3/4	0	Tensioned 9-5/8-in. casing to 885 000. Second stage cemented with 1200 sacks. WOC.
456	8/20/81	13 933	8-3/4	0	Flow nipple installed on 9-5/8-in. casing. Trip in hole.
457	8/21/81	13 933	8-3/4	0	Drilling out cement.
458	8/22/81	13 933	8-3/4	0	Drilling out cement.

Day No.	Date	Measured Depth At 2400 h (ft)	Hole/Bit Size (in.)	Days Footage (ft)	Remarks
459	8/23/81	13 933	8-3/4	0	Schlumberger ran CBL and neutron density-gamma logs.
460	8/24/81	13 933	8-3/4	0	Ran bit to bottom. Flushed with high pH fluid. Displaced hole with clean, fresh water.
461	8/25/81	13 933	8-3/4	0	Layed down pipe. Released rig at 0600 am.

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APPENDIX B

DETAILED EE-3 BIT RECORD

List of Appreviations:

BHA	bottom-hole assembly
EYE	Scientific Drilling Control steering tool
HTC	Hughes Tool Co.
HWDP	Hevi-Wate Drill Pipe
POH	pull out of hole
Sec	Dressers Security
STC	Smith Tool Co.
TIH	trip in hole
TOH	trip out of hole
DC	drill collar
DP	drill pipe

Bit Number	Size	Make	Type	Jets	Depth Out	Feet Drilled	Rotating Hours	Ft/Hr	Bit Weight 1000#	Pounds Per Dia in.	RPM	Pump Rate (GPM)	Pump Pressure (PSI)	HHP/in.^{2}	Mud Weight	Plastic Viscosity	Condition	Hrs on Shock Sub	Hrs on Jars	Deviation	BHA	Remarks
1	26"	STC	DG	Ctr Circ	890	785	73	10.75	5-50	Avg 1058	40-110	850	800	-	9.2	6	5-6-I	73	22	2-N-10-E	Bit, Bit sub, 9"DC, SS, 8" monel, 5-9" DC's, 14-8" DC's, Jars, X-0, 5-6-3/4"DC's	Pulled to change BHA; spud 5/22/80, bit balling problems
2	26"	STC	2JS	22-22-22	1066	176	24	7.33	45	1731	40-60	829	1200	0.414	9.0	6	2-2-I	97	46	1-1/4°N-55-E	Bit, X-0, Bit sub, Stab, SS, Stab, 8" monel, stab, 6-9" DC's, 14-8" DC's, Jars, X-0, 6-6-3/4" DC's, HWDP	Formation too soft; bit balled up
3	26"	STC	DG	Ctr Circ	1570	504	49.5	10.18	65-85	Avg 2500	90	875	1100	-	9.2	10	5-6-I	146.5	95.5	1°-N-43°-E	"	-
RR#2	26"	STC	2JS	22-22-22	1923	353	44.5	7.93	75	2884	65	790	1200	0.372	9.1	10	2-4-I	191	140		"	Lost returns at 1923'; trip out
4	17-1/2"	STC	DJS	Open																	"	Wash and ream 26" hole
RR#4	17-1/2"	STC	DJS	Open																	"	"
RR#2	26"	STC	2JS	22-22-22																	"	Wash and ream; drill cement 26" hole
RR#4	17-1/2"	STC	DJS	18-18-20	1989	66	2	33	55	3143	90	594	1200	0.605	Water	-	3-4-I	201	150	-	Bit, X-0, 3 pt, X-0, SS, stab, monel, stab, 6-9" DC's, 14-8" DC's, jars, X-0, 6-6-3/4" DC's, 18 jts HWDP	Drill cement 1534' to 1903'; lost returns; drill w/water to 1989'; POH to cement
RR#4	17-1/2"	STC	DJS	15-15-18	2141	152	5	30.4	60-70	3714	75	378	500	0.298	"		6-5-I	208	157	-	"	Drill cement 1825' to 1930'; no returns; drill 1989' to 2141' w/no returns
5	17-1/2"	STC	DJS	13-13-13	2407	266	4.5	59.1	60-90	4285	120	378	600	0.6616	"		8-3-I	212.5	161.5		"	RR from Sigma Mesa; drilling w/no returns
6	17-1/2"	STC	4JS	11-11-11	2566	159	13	12.2	85	4857	65	459	2000	2.616	"		5-2-1/8	225.5	174.5		"	Drill granite without returns
7	17-1/2"	STC	V2J	Open																	"	Clean 17-1/2" hole to run casing
8	12-1/4"	STC	L4HJ	Open	2566																"	Drill stage collar and shoe jts
9	12-1/4"	Sec	H-100	11-11-12	2882	316	45.5	6.9	25.70	Avg 5306	40-65	418	2000	3.31	Water		5-8-1/4	45.5	-	1-1/2°N-60°E	Bit, 6 pt, X-0, SS, 3 pt, monel, 3 pt, 14-8" DC's, X-0, 6-6-3/4" DC's, 20 jts HWDP	Run 25-30,000 on bit until below casing
10	12-1/4"	Sec	H-100	13-15-11	3445	563	57	9.9	70	5714	65	441	1500	2.29	"		6-4-1/4	102.5	-	2°N50°W	Bit, 6 pt, X-0, SS, 3 pt, monel, 3 pt, 14-8" DC's, X-0, 10-6-3/4" DC's, 20 jts HWDP	Pulled because of increasing deviation
11	12-1/4"	STC	F-4	14-14-14	3631	186	23.5	7.9	40-60	Avg 4081	55-60	441	1400	1.57	"		6-2-1/4	125.5	-	2-1/2°N-55°W	"	Wireline broke on survey tool; had to pull; buttons on bit wore down, not broke
12	12-1/4"	STC	Q9JL	13-13-B	3734	103	18	5.72	60	5306	65-75	487	1400	Air Bit	"		4-4-I	143.5	-	3-1/4°N-70°W	"	Drill collars twisted off
RR#12	12-1/4"	STC	Q9JL	13-13-B	3749	15	3-3/4	4.0	45	3673	70	@93% 456	1450	Air Bit	"	0	6-5-1/4	147.25	-	No survey	Bit, 6 pt, 3 pt, X-0, SS, 3 pt, monel, 3 pt, 14-8" DC, X-0, 10-6-3/4" DC, 20 HWDP	Cracked monel DC; limited WOB below 3723' to control deviation
13	12-1/4"	STC	F5	14-14-B	4062	313	38-1/2	8.1	45	3673	70	@93% 433	1830	3.4	"	0	8-SE-1/4	(Laid Dnss)	-	See reports	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, 8" DC, 3 pt, 13-8" DC, X-0, 10-6-3/4" DC, 20 HWDP	Cracked 6-3/4" DC; as above
14	12-1/4"	Sec	H100	14-14-B	4342	280	30	9.3	55-65	4490/5306	65	@93% 407	1950	2.8	"	0	7,SF-1,2,3,1/4,#1CL	" "	-	" "	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, 8" DC, 3 pt, 13-8" DC, X-0, 9-6-3/4" DC, 20 HWDP	Lost pump press; as above
15	12-1/4"	HTC	J44	14-14-B	4358	16	1-1/2	10.7	30-55	2449/4490	30-65	@93% 407	1950	2.8	"	0	1-SE-I	" "	-	None	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, 8" DC, 3 pt, 13-8" DC, X-0, 8-6-3/4" DC, 20 HWDP	Lost pump press; breaking in bit
RR#15	12-1/4"	HTC	J44	14-14-B	4379	21	1-1/2	14.0	55	4490	65	@93% 453	1800	Leak in DP	"	0	Not surfaced	" "	-	None	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, 8" DC, 3 pt, 13-8" DC, X-0, 8-6-3/4" DC, 20 HWDP	Lost pump press; crack in HWDP
RR#15	12-1/4"	HTC	J44	14-14-B	4550	171	15-1/4	11.2	55	4490	65	@93% 453	1800	3.1	"	0	5-SE-I	" "	-	See reports	"	Pulled due to gauge wear
16	12-1/4"	STC	Q9JL	12-12-B	4613	63	4-1/4	14.8	50	4082	65	@85% 423	1400	Air Bit	"	0	Not surfaced	151.50	-	" "	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, SS, 8" SDC, 3 pt, 14-8" DC, 8-6-3/4" DC, 19 HWDP	Lost pump press; cracked 6-3/4" DC
RR#16	12-1/4"	STC	Q9JL	12-12-B	4856	243	32-3/4	7.4	50-55	4082-4490	65	@85% 423	1400	Air Bit	"	0	6,7, 1/16	184.25	-	" "	Bit, 6 pt, 3 pt, X-0, 15' x 8" monel, 3 pt, SS, 8" SDC, 3 pt, 14-8" DC, 4-6-3/4" DC, 19 HWDP	Pulled due to hours
17	12-1/4"	STC	F5	14-14-B	5203	347	35-1/4	9.8	55	4490	65	@93% 437	1750	3.5	"	0	7, SE, 1/8	219.50	-	" "	"	"
18	12-1/4"	HTC	J55	14-14-B	5248	45	3	15.0	55	4490	70	@93% 437	1750	3.5	"	0	Not surfaced	222.50	-	" "	Bit, 6 pt, 3 pt, X-0, 15'-8" monel, 3 pt, SS, 9'-8" SDC, 3 pt, 14-8" DC, 4-6-3-4" DC, 19 HWDP	Lost pump press; top jt HWDP cracked
RR#18	12-1/4"	HTC	J55	14-14-B	5420	172	13-1/2	12.7	55	4490	70	@93% 437	1750	3.5	"	0	Not surfaced	236.00	-	" "	Bit, 6 pt, 3 pt, X-0, 15'-8" monel, 3 pt, SS, 9'08" SDC, 3 pt, 14-8" DC, 4-6-3/4" DC, 18 HWDP	Lost pump press; bottom 6-3/4" DC, and 6th-8" DC
RR#18	12-1/4"	HTC	J55	14-14-B	5538	118	11-1/4	10.5	55	4490	65	@93% 437	1750	3.5	"	0	8,SE,1/8, 50% Broken Inserts	247.25	-	" "	Bit, 6 pt, 3 pt, X-0, 15'-8" monel, 3 pt, SS, 9'-8" SDC, 3 pt, 16-8" DC, 17 HWDP	Pulled due to torque
19	12-1/4"	HTC	J55	14-14-B	6334	196	40	19.9	55/45	Avg 4082	65	@93% 437	1750	3.5	"	0	6, SE, 1/4	40	-	" "	Bit, 6 pt, 3 pt, SS, X-0, 3 pt, 30'-8" monel, 3 pt, 16'8" DC's, X-0, 17 jts HWDP	Pulled to run gyrosurvey
20	12-1/4"	STC	4JS	14-14-B	6444	110	5-1/2	20.0	45	3673	65	@93% 437	1750	3.5	"	0	2-SE-1/8	45-1/2	-	" "	"	Twisted off 8" DC
21	12-1/4"	STC	Q9JL	14-14-14	6520	76	15	5.1	15	1224	1.Baker Motor	@93% 361	900	Air Bit	"	0	5-5-1/8	45-1/2	-	" "	Bit, X-0, Baker Motor, float sub, X-0, 2° bent sub, X-0, 30'-8" monel, 11-8" DC's, X-0, 17 jts HWDP	Directional drilling
22	12-1/4"	Sec	H8J	14-14-14	6649	129	7-1/2	17.2	15	1224	2.Baker Motor	@93% 361	900	Air Bit	"	0	4-5-I	45-1/2	-	" "	"	Trip to use EYE tool
RR#20	12-1/4"	STC	4JS	14-14-B	6710	61	9-1/2	6.4	25	2041	65	@93% 394	1600	2.55	"	0	4-6-1/4	55	-	" "	Bit, 3 pt, SS, X-0, 3 pt, monel, 3 pt, 8-8" DC's, X-0, 9 jts HWDP	Hardbanding drill collars; reaming runs
23	12-1/4"	STC	Q9JL	14-14-14	6809	99	20-1/2	4.8	15	1224	3.Baker Motor	@93% 351	800	Air Bit	"	0	6-6-I	55	-	" "	Bit, X-0, Baker Motor, float sub, X-0, 2° bent sub, X-0, 30'-8" monel, 8" DC's, X-0, HWDP	-
24	12-1/4"	Sec	H8J	14-14-14	6868	59	2-1/2	23.6	18	1469	4.Dyna-Drill	@93% 371	1100	Air Bit	"	0	2-4-I	55	-	" "	Bit, Dyna-Drill, 2° bent sub, X-0, 30'7"8" monel, 10'-8" DC's, X-0, 9 jts HWDP	Plugged bit and motor w/cuttings on connection
RR#22	12-1/4"	Sec	H8J	14-14-14	6903	35	5	7.0	30	2449	65	@93% 476	1100	Air Bit	"	0	4-6-I	5	-	" "	Bit, 3 pt, SS, X-0, 3 pt, monel, 3 pt, 12-8" DC's, X-0, 9 jts HWDP	Reaming run
RR#24	12-1/4"	Sec	H8J	14-14-14	7114	211	15	14.1	15	1224	5.Dyna-Drill	@93% 385	1150	Air Bit	"	0	8-8-1	5	-	" "	Bit, Dyna-Drill, float sub, X-0, 2° bent sub, X-0, 8" monel, 10-8" DC's, X-0, 9 jts HWDP	-
25	12-1/4"	HTC	Y-44	14-14-B	7179	65	4-1/2	14.4	35	2857	65	@93% 409	1700	2.83	"	0	2-3-1/8	-	-	" "	Bit, 3 pt, 5 DC, 3 pt, monel, 3 pt, 18-8" DC's, X-0, 17 jts HWDP	Reaming run
26	12-1/4"	STC	5JS	15-15-15	7269	90	13	6.9	20	1633	6.Baker Motor	@93% 351	1000	0.613	"	0	5-4-1/8"	-	-	" "	Bit, X-0, Baker Motor, flcat sub, X-0, 2° bent sub, X-0, 8" monel, 9-8" DC's, X-0, 17 jts HWDP	Motor stalled
27	12-1/4"	HTC	X-44	14-14-14	7269	0	1	-	4	-	7.Baker Motor	@93% 351	1000	0.613	"	0	pinched	-	-	" "	"	Hit reduction in hole size at the bottom of the casing; bit pinched motor bent
28	12-1/4"	Sec	H8J	15-15-15	7337	68	9	7.6	20-30	Avg 2041	8.Navi-Drill	@93% 404	1100	Air Bit	"	0	6-6-1/8"	-	-	" "	Bit, Navi-Drill, float sut, X-0, 2° bent sub, X-0, 8" monel, 9-8" DC's, X-0, 17 jts HWDP	Quit drilling
29	12-1/4"	Sec	H8J	14-14-14	7427	90	7-1/2	12	15-20	Avg 1429	9.Navi-Drill	@93% 409	950	Air Bit	"	0	8-8-1/4"	-	-	" "	"	Cone locked up

APPENDIX B (CONT)

Bit Number	Size	Make	Type	Jets	Depth Out	Feet Drilled	Rotating Hours	Ft/Hr	Bit Weight 1000#	Pounds Per Dia in.	RPM	Pump Rate (GPM)	Pump Pressure (PSI)	HHP/in.^{2}	Mud Weight	Plastic Viscosity	Condition	Hrs on Shock Sub	Hrs on Jars	Deviation	BHA	Remarks
30	12-1/4"	Sec	H8J	14-14-14	7482	55	6	9.2	10	816	10.Navi-Drill	@93% 409	950	Air Bit	Water	0	8-8-1/2"	-	-	" "	Bit, Navi-Drill, float sub, X-0, 2° bent sub, X-0, 8" monel, 9-8" DC's, X-0, 17 jts HWDP	Cone locked up
RR#25	12-1/4"	HTC	X-44	14-14-B	7542	60	5-1/2	10.9	60	5306	65	@93% 385	1600	-	"	0	4-5-1/4"	10.5	-	" "	Bit, 3 pt, SS, 3 pt, 30'-8" monel, 3 pt, 18-8" DC, X-0, 17 jts HWDP	Put rig on standby; out of funds
31	12-1/4"	STC	F5	14-13-B	7845	303	25-3/4	11.8	45-63	3673-5143	65-45	@93% 384	1850	2.75	"	0	6-SE-1/8"	25.75	25.75	" "	Bit,BH, 3 pt, X-0,X-0,SS,X-0, 30'-6-3/4" monel, 30'-6-3/4" DC, X-0, 3 pt, 30'-8" DC, 3 pt, 16-8" DC, 7-3/4 jars, X-0, 17 jts HWDP	Pulled to make motor run
32	12-1/4"	Sec	H8J	14-14-14	7856	11	1	11.0	5-10	408-816	11.DynaTurbine	@93% 450	1530	1.00	"	0	2-3-3/16"	-	26.75	" "	Bit, X-0, Turbine, X-0, BS, MSS, SS, X-0, 8" monel 30', 9-8" DC, jars, X-0, 17 jts HWDP	Pulled due to steering tool failure
33	12-1/4"	STC	Q9JL	20-20-20	7883	27	6.5	4.15	10-15000	Avg 1020	12.Dyna-Drill	385	1050	Air Bit	8.33	0	5-7-I	-	33.25		Bit, Dyna-Drill, X-0, X-0, float, X-0, 1-1/2° bent sub, mule shoe, X-0, 8" monel, 11-8" DC's, jars, X-0, 17 jts HWDP	Dyna Drill quit
34	12-1/4"	STC	Q9JL	20-20-20	7905	22	4.0	5.50	5-20000	Avg 1224	13.Dyna-Drill	385	1050	Air Bit	8.33	0	5-5-I	-	37.25			Eye tool quit
35	12-1/4"	STC	Q9JL	20-20-20	7940	35	2.0	17.50	20000	1633	14.Dyna-Drill	385	1000	Air Bit	8.33	0	4-6-I	-	39.25		"	Dyna Drill quit
36	12-1/4"	STC	Q9JL	24-24-24	8052	112	4.5	24.89	15000	1224	15.Navi-Drill	404	900	Air Bit	8.33	0	5-7-1/8	-	43.75		Bit, Navi-Drill, X-0, X-0, float, X-0, 1-1/2° bent sub, mule shoe, X-0, 8" monel, 11-8" DC's, jars, X-0, 10 jts HWDP	Good run finally
RR#34	12-1/4"	STC	Q9JL	24-24-24	8052	0	8.5	-	5-10000	-	40	443	600	Air Bit	8.33	0	5-5-1/8	19	52.25	16-1/4°N°9E	Bit, 6 pt, SS, 3 pt, 8" monel, 3 pt, 11-8" DC's, jars, X-0, 17 jts HWDP	Reaming torque 500 amps, Drilco 8" shock sub bad
37	12-1/4"	STC	Q9JL	24-24-24	8062	10	1	10	15000	1224	16.Navi-Drill	366	1050	Air Bit	8.33	0	2-2-I	-	53.25		Bit, Navi-Drill, X-0, X-0, float, X-0, 1-1/2° bent sub, mule shoe, X-0, 8" monel, 11-8" DC's, jars, X-0, 17 HWDP	Could not orient because of torque
RR#34	12-1/4"	STC	Q9JL	24-24-24	8067	5	-	10.00	10000	-	55	443	600	Air Bit	8.33	0	5-5-1/8	-	57.25		Bit, 6 pt, 5 DC, 3 pt, 8" monel, 3 pt, 11-8" DC's, jars, X-0, 17 jts HWDP	Ream hole again
R#37	12-1/4"	STC	Q9JL	24-24-24	8159	92	5	18.40	30000	2449	17.Navi-Drill	375	1050	Air Bit	8.33	0	5-6-I	-	62.25		Bit, Navi-Drill, X-0, X-0, float, X-0, 1-1/2° bent sub, mule shoe, X-0, 8" monel, 11-8" DC's, jars, X-0, 17 jts HWDP	
38	12-1/4"	STC	Q9JL	20-20-20	8170	11	.50	22.00	30000	2449	18.Navi-Drill	385	1100	Air Bit	8.33	0	2-2-I	-	62.75			Navi-Drill froze up
RR#38	12-1/4"	STC	Q9JL	20-20-20	8265	95	3.50	27.14	30000	2449	19.Navi Drill	385	1100	Air Bit	8.33	0	4-6-I	-	66.25		"	
RR#34	12-1/4"	STC	Q9JL	20-20-20	8265	0	Ream 16	-	5000	-	60	457	700	Air Bit	8.33	0	5-5-1/4	-	82.25	16-3/4°N81E	Bit, 6 pt, SDC, 3 pt, 8" monel, 3 pt, 14-8" DC's, jars, X-0, 17 jts HWDP	Ream motordrill hole; reamed hard
39	12-1/4"	STC	F-5	13-13-12	8407	142	10-1/2	13.52	50000	4081	60	450	1650	2.56	8.33	0	2-2-1/8	-	92.75	17-1/4°N88E	"	Trip for hole in drill string
40	12-1/4"	STC	Q9JL	16-16-16	8407	0	2-1/2	-	-	-	20.Dyna-Drill	362	1800	Air Bit	8.33	0	Pinched	-	2.5		Bit, bit sub, turbine, X-0, X-0, X-0, float, 12-8" DC's, jars, X-0, 17 jts HWDP	Tachometer not working; could not get turbine to drill
41	12-1/4"	STC	Q9JL	16-16-16	8407	0	0	-	-	-	21.Dyna-Drill	346	2300	Air Bit	8.33	0	1-2-1/4	-	2.5			Hit obstruction at 7130'; jar loose; ream 7130' to 7230' w/turbine tachometer working
RR#39	12-1/4"	STC	F-5	13-13-12	8727	320	32-1/2	9.85	50000	4081	55	438	1650	2.32	8.33	0	6-5-1/4	32-1/2	34.5	17-1/4°N83E	Bit, 6 pt, SS, 3 pt, float sub, X-0, 8" monel, 3 pt, 14-8" DC's, jars, X-0, 17 jts HWDP	Pulled to run building assembly
42	12-1/4"	HTC	X-44	12-12-14	8827	100	8-1/2	11.76	45000	3673	50	428	1600	2.13	8.33	0	2-4-1/4	8-1/2	43		Bit, 3 pt, X-0, SS, X-0, 1-6-3/4" monel, 1-6-3/4" DC, X-0, 3 pt, 1-8" DC, 3 pt, 11-8" DC, jars, X-0, 17 jts HWDP	Twisted off box on 6-3/4" DC
43	12-1/4"	STC	F-4	12-12-13	8925	98	10-1/2	9.33	50000	4082	50	414	1650	2.17	8.33	0	2-4-1/8	19	10-1/2		Bit, 3 pt, float, X-0, X-0, SS, X-0, 1-6-3/4" monel, 1-6-3/4" DC, X-0, 3 pt, 1-8" DC, 3 pt, 11-8" DC's, jars, X-0, 17 jts HWDP	Building too fast
RR#43	12-1/4"	STC	F-4	12-12-13	9142	217	25-1/2	8.51	55000	4490	50	433	1800	2.48	8.33	0	7-6-1/4	-	36		Bit, 6 pt, float, X-0, 30'-9" DC, X-0, 3 pt, X-0, 30' monel, 3 pt, 13-8" DC, jars, X-0, 20 jts HWDP	Trip for bit
44	12-1/4"	STC	F-5	12-12-13	9234	92	11	8.36	55000	4490	50	433	1800	2.48	8.3 +	0	4SE-1/8	-	47		Bit, 6 pt, float, X-0, 30'-9" DC, X-0, 3 pt, X-0, 8"30' monel, 3 pt, 13-8" DC, 7-3/4" jars, X-0, 20 HWDP	Pulled due to excessive hole drag
RR#44	12-1/4"	STC	F-5	12-12-13	9348	114	13-1/4	8.60	55000	4490	50	418	1700	2.16	8.3 +	0	8, SF-1/4 #1	-	60-1/4			Trip for bit
45	12-1/4"	HTC	J-55	12-12-14	9547	199	19-1/2	10.21	55-58	4490-4735	50	416	1500	1.96	8.3 +	0	7, SF, 1/8 #1,2	-	79-3/4		"	Trip for building assembly
46	12-1/4"	STC	F-4	3-12	9728	181	28-1/4	6.41	35-50	Avg 3469	55	404	1750	1.69	8.3 +	0	6-6-1/4	-	108	26-3/4°N72E	Bit, 3 pt, float, X-0, X-0, X-0, 6-3/4" monel, 1-6-3/4" DC, X-0, 3 pt, 13-8" DC's jars, X-0, 20 jts HWDP	Walking to left too fast
47	12-1/4"	STC	F-4	3-12	9850	122	20	6.10	40000	3265	50	385	1650	1.58	8.3 +	0	4-4-1/8	-	128	26-1/2°N67E	Bit, 3 pt, float, X-0, X-0, X-0, 6-3/4" monel, X-0, 3 pt, 13-8" DC's, jars, X-0, 20 jts HWDP	Pulled to make motor run
48	12-1/4"	HTC	HH-77	Open	9879	29	1	29.0	20000	1633	22.Navi-Drill	385	1100	Air Bit	8.3 +	0	6-4-1/8	-	129		Bit, Navi Drill, X-0, X-0, float sub, X-0, 1-1/2° bent sub, WSS, X-0, 1-8" monel, 13-8" DC's, jars, X-0, 20 jts HWDP	Motor stopped
49	12-1/4"	STC	Q9JL	24-24-24	9879	0	0	-	-	-	23.Navi-Drill	-	-	Air Bit	8.3 +	0	1-1-I	-	129		"	Motor wouldn't drill
50	12-1/4"	STC	F-5	12-12-13	9924	45	4	11.25	55000	4490	45	414	1700	2.17	8.3 +	0	2-2-1/8	-	4	25°N68E	Bit, 3 pt, float sub, X-0, X-0, 1-6-3/4" monel, X-0, 6-3/4" SDC, X-0, 3 pt, 13-8" DC's, jars, X-0, 18 jts HWDP	Lost circulation; pulled to run temperature survey
RR#50	12-1/4"	STC	F-5	12-12-13	9987	63	6	10.5	55000	4490	50	414	1700	2.17	8.3 +	0	4-2-1/8	-	10	24°N67E	"	Angle dripping; pulled to run turbine
RR#50	12-1/4"	STC	F-5	Open	10017	30	3-1/2	8.6	45000	3673	60	433	700	-	8.3 +	0	5-8-1/8	-	13-1/2		Bit, TB, 6 pt, SDC, 3 pt, X-0, monel, short monel, 13-8" DC's, jars, X-0, 18 jts HWDP	Run to cure lost circulation
RR#49	12-1/4"	STC	Q9JL	12-12-12	10017	0	1-1/2	-	-	-	24.Dyna Turbine	409	1800	Air Bit	8.3 +	0	3-3-1/8	-	15		Bit, X-0, turbodrill, X-0, X-0, X-0, FS, X-0, X-0, 1-1/2° BS, MSS, X-0, monel, 13-8" DC's, jars, X-0, 17 jts HWDP	Trip for hole in drill string
51	12-1/4"	STC	Q9JL	12-12-12	10017	0	1	0		-	25.Dyna Turbine	433	1850	Air Bit	8.3 +	0	1-1-I	-	16		"	Turbine would not turn
RR#51	12-1/4"	STC	Q9JL	18-18-18	10116	99	5	19.8	10-15000	-	26.Maurer Turbine	385	1750	-	8.3 +	-	6-8-1/2	-	21		Bit, turbodrill, 1-1/2° BS, MSS, X-0, 8"-30' monel, 13-8" DC, jars, X-0, 18-5" HWDP	Pulled for new bit
52	12-1/4"	STC	Q9JL	Open	10116	Ream-0	10-1/2	-	-	-	-	414	600	-	8.3 +	-	?	-	31-1/2		Bit, JB, 3 pt, float, X-0, 8"-30" monel, 13-8" DC, jars, X-0, 18-5" HWDP	Ream hole
53	12-1/4"	STC	Q9JL	18-18-18	10123	7	4	1.8	15000	-	27.Maurer Turbine	385	1750	-	8.3 +	-	2-2-1/4	-	35-1/2		Bit, turbo, 1-1/2° BS, MSS, X-0, 30'-8" DC, 13-8" DC, jars, X-0, 18-5" HWDP	Turbodrill locked up
54	12-1/4"	STC	Q9JL	18-18-18	10150	27	1-1/2	18	15000	-	28.Maurer Turbine	385	1700	-	8.3 +	-	0	-	37		"	Bit locked up
55	12-1/4"	STC	Q9JL	Open	10150	Ream 0	2	0	8000	-	45	414	700	-	8.3 +	-	0	0	39		Bit, BH 3 pt, FS, X-0, 30'-8" monel, 13-8" DC, jars, X-0, 18-5" HWDP	Ream hole
56	12-1/4"	STC	Q9JL	18-18-18	10204	54	4	13.5	Unknown	-	29.Maurer Turbine	395	1850	-	8.3 +	-	6-5-1/2	-	43		Bit, turbo, 1-1/2° FS, MSS, X-0, 8"-30' monel, 13-8" DC, jars, X-0, 18-5" HWDP	Pulled for new bit
57	12-1/4"	STC	4JS	12-12-B	10303	42	2-1/4	18.7	50000	4082	65	313	2000		8.3 +	-	2-SF-1/4 #3	-	45-1/4		Bit, BH 3 pt, FS, X-0, 30'-8" monel, 15'-8" monel, 13-8" DC, jars, X-0, 18-5" HWDP	Pulled for motor correction
58	12-1/4"	STC	Q9JL	18-18-18	10334	31	1	31.0	10000	1224	30.Maurer Turbine	424	2200	-	8.3 +	-	3-5-1/16	-	46-1/4		Bit, turbo, 2° BS, MSS, X-0, 8'-29" monel, 8"-15' monel, 13-8" DC, jars, X-0, 18-5" HWDP	Motor locked up
59	12-1/4"	Sec	H100	18-18-18	10378	44	1-1/4	35.2	10000	816	31.Maurer Turbine	361	1550	-	-	-	2-SE-1/4	-	50		Bit, turbo, 1-1/2° BS, MSS, X-0, 8"-29' monel, 8"-15' monel, 13-8" DC's, jars, X-0, 18-5" HWDP	Dropping angle
60	12-1/4"	STC	Q9JL	18-18-18	10417	39	2	19.5	5-15000	408-1224	Maurer Turbine	361	1500	-	-	-	5-5-1/2	-	57		Bit, turbo, 2° BS, MSS, X-0, 8"-29' monel, 8"-15' monel, 13-8" DC's, jars, X-0, 18-5" HWDP	Wireline truck lost power take-off
61	12-1/4"	Sec	GM88	18-18-18	10372	0	Ream 2-1/2	-	2-7000	163-571	45	-	-	-	-	-	1-1-1/8	-	59-1/2		Bit, 6 pt, X-0, FS, 29'-8" monel, 15'-8" monel, 13-8" DC's, jars, X-0, 18-5" HWDP	Hole too tight to ream; twist off
62	12-1/4"	Sec	GM88	Open	10417	30	Ream 1/2	-	-	-	45	415	700	Air Bit	8.3	-	2-2-1/8	-	60	24-3/4°N66E	Bit, JB, X-0, X-0, 2-6-3/4" monel, 3-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	Clean hole up after fishing job
63	12-1/4"	STC	Q9JL	24-24-24	10463	46	2	23.0	15000	1224	Maurer Turbine	632	1500	Air Bit	8.3	-	4-5-1/2	-	62		Bit, turbo, 2° bent sub, MSS, X-0, X-0, X-0, 2-6-3/4" monel, 3-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	Turbine gave out
RR#62	12-1/4"	Sec	GM88	Open	10463	0	Ream 4-1/2	-	-	-	45	415	700	Air Bit	8.3	-	2-2-1/8	-	66-1/2	24-3/4°N66E	Bit, JB, X-0, X-0, 2-6-3/4" monel, 3-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	Ream hole
64	12-1/4"	STC	Q9JL	24-24-24	10489	26	2	13.0	5-10000	612.2	Maurer Turbine	362	1500	Air Bit	8.3	-	4-6-3/8	-	68-1/2		Bit, turbo, 1-1/2° bent sub, MSS, X-0, X-0, X-0, 2-6-3/4" monel, 3-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	
RR#62	12-1/4"	Sec	GM88	15-15-15	10528	29	7	7.1	35000	2887	55	394	1150	Air Bit	8.3	-	4-6-1/4	-	74-1/2	26-1/4°N66E	Bit, X-0, 3 pt, X-0, X-0, 2-6-3/4" monel, 6-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	
65	12-1/4"	STC	Q9JL	24-24-24	10528	0	0	-	-	-	Maurer Turbine	-	-	Air Bit	8.3	-	1-1-I	-	74-1/2		Bit, turbo, 1-1/2° bent sub, MSS, X-0, X-0, X-0, 3-6-3/4" monel, 3-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	Could not get turbine to turn
66	12-1/4"	HTC	HH-99	Open	Left in	0	0	0	0	0		399	1150	-	8.3	-	Not seen	-	-	-	Bit, 3 pt, X-0, 1-6-3/4" DC, X-0, 3 pt, X-0, 2-6-3/4" DC's, 9 jts HWDP, jars, 6 jts HWDP	Twisted off while reaming lost bit in hole
67	12-1/4"	HTC	HH-99	Open	" "	-	-	-	-	-	-	-	-	-	8.3	-	1-1-I	-	-	-	Bit, underreamer, X-0, 6-8" DC's, X-0, jars, X-0	Run on underreamer, would not go through casing
68	12-1/4"	STC	DSJ	Open	9770	32	1	32	5000	408	65	332	900	-	8.3	-	2-2-I	-	-	-	Bit, X-0, 6-8" DC's, X-0, jars, X-0	Drill cement plug
RR#68	12-1/4"	STC	DSJ	Open	9750	562	22	25.5	5-1000	Avg 612	65	423	1000	-	8.3	-	2-6-1/8	-	-	-	"	Drill cement; plugged bit w/cuttings
69	12-1/4"	STC	DSJ	Open	9998	559	10	55.9	5000	408	60	423	1000	-	8.3	-	2-4-I	-	-	-	"	Drill cement plug - soft
RR#69	12-1/4"	STC	DSJ	Open	10100	543	15.5	35.0	5000	408	60	390	1000	-	8.3	-	2-6-I	-	-	-	Bit, X-0, float, 6-8" DC's, X-0, jars, X-0	"
70	12-1/4"	STC	DTJ	Open	9550	122	4	30.5	5000	408	60	407	1000	-	8.3	-	2-2-I	-	-	-	Bit, JB, X-0, float sub, 6-8" DC's, X-0, jars, X-0	Drill cement plug - still soft
RR#70	12-1/4"	STC	DTJ	Open	9820	270	8.5	31.8	5000	408	60	423	1100	-	8.3	-	2-4-I	-	-	-	Bit, X-0, float sub, 6-8" DC's, X-0, jars, X-0	Drill cement plug - still soft
RR#70	12-1/4"	STC	DTJ	Open	9725	597	29	20.5	5000	408	60	448	1400	-	8.3	-	2-6-1/8	-	-	-	Bit, JB, X-0, float sub, 6-8" DC's, X-0, jars, X-0	Drill cement plug - still soft
71	9-7/8"	STC	Q9JL	16-16-16	9780	55	8	6.9	2000	163	Dyna Drill	351	1000	-	8.3	-	3-3-1/4	-	-	-	Bit, X-0, DynaDrill, X-0, 2-8" monel, X-0, jars, X-0, 12 jts HWDP	Sidetrack attempt, time drill
72	12-1/4"	HTC	HH77	Open	9800	76	8	9.5	10000	816	60	403	1000	-	8.3	-	2-2-1/4	-	-	-	Bit, junk basket, X-0, 6-8" DC's, X-0, jars, X-0, 12 jts HWDP	Ream out sidetrack hole
RR#72	12-1/4"	HTC	HH77	Open	9500	121	9	13.4	2-15000	Avg 408	60	448	900	-	8.3	-	2-2-I	-	-	-	Bit, junk basket, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Drill cement - still soft
73	12-1/4"	STC	DSJ	Open	9144	66	2	33.0	5-10000	Avg 612	60	395	950	-	8.3	-	2-2-I	-	-	-	"	Drill cement - still soft
74	7-7/8"	STC	Core Bi		9158	15	1	15.0	3000	-	36	124	-	-	8.3	-	Good	-	-	-	Core bit, core bbl, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Core cement
RR#73	12-1/4"	STC	DSJ	Open	9250	92	2-1/2	36.8	10000	816	60	395	850	-	8.3	-	2-2-1/8	-	-	-	Bit, junk basket, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Drill cement
RR#74	7-7/8"	STC	Core Bit		9266	16	1-1/2	10.7	10000	816	35	124	-	-	8.3	-	Good	-	-	-	Core bit, core bbl, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Core cement - looks hard
RR#73	12-1/4"	STC	DSJ	Open	9300	34	1	34.0	7000	571	60	395	850	-	8.3	-	2-2-1/8	-	-	-	Bit, junk basket, X-0, 3-8" DC's, X-0, jars, X-0, 12 jts HWDP	Drill cement
75	8-3/4"	STC	7GA	16-16-16	9304	4	10-1/2	0.4	Time Drill	-	Dyna-Drill	344	950	-	8.3	-	1-3-1/8	-	-	-	Bit, DD, DynaFlex floats, MSS, monel, monel, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Attempting sidetrack
76	8-3/4"	Reed	82JA	14-14-14	9319	15	10-1/2	1.4	Time Drill	-	Dyna-Drill	344	1500	-	8.3	-	2-4-I	-	-	-	"	"
77	8-3/4"	Chris	Diamond		9323	4	5-1/2	0.7	Time Drill	-	Dyna-Drill	329	1400	-	8.3	-	Good	-	-	-	"	Attempting sidetrack; diamond bit grooved on top
RR#77	8-3/4"	Chris	Diamond		9323	0	2		-	-	Dyna-Drill	329	1400	-	8.3	-	Good	-	-	-	"	Suspected junk in hole; bit more grooved on top
78	8-3/4"	Sec	S35J	Open	9325	2	1/2	4.0	-	-	-	395	850	-	8.3	-	Good	-	-	-	Bit, JB, float sub, MSS, monel, monel, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Drill on junk?
RR#77	8-3/4"	Chris	Diamond		9329	4	7.5	0.5	Time Drill	-	Dyna-Drill	315	1000	-	8.3	-	Good/worn on gauge	-	-	-	Bit, DynaDrill, float, MSS, monel, monel, X-0, 5-8" DC's, X-0, jars, X-0, 12 jts HWDP	Attempting sidetrack
79	8-3/4"	Reed	73JA	13-13-13	9339	10	8.5	1.2	Time Drill	-	Dyna-Drill	337	1400	-	8.3	-	Lost 3 nose cones	-	-	-		Lost 3 nose cones; attempting sidetrack
R75	8-3/4"	STC	7GA	16-16-16	9382	43	7.0	6.1	5000	408	Dyna-Drill	337	1400	-	8.3	-	6-6-1/8	-	-	-	"	Buttons worn down

APPENDIX B (CONT)

Bit Number	Size	Make	Type	Jets	Depth Out	Feet Drilled	Rotating Hours	Ft/Hr	Bit Weight 1000#	Pounds Per Dia in.	RPM	Pump Rate (GPM)	Pump Pressure (PSI)	HHP/in.^{2}	Mud Weight	Plastic Viscosity	Condition	Hrs on Shock Sub	Hrs on Jars	Deviation	BHA	Remarks
80	8-3/4"	STC	7GA	16-16-16	9386	4	0.5	8.0	10000	816	45	402	1200	-	8.3	-	2-2-1/8	-	-	-	Bit, 3 pt, float, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 7-8" DC's. X-O, jars, X-O, 12 jts HWDP	Drilling too fast; decided to run motor
RR#80	8-3/4"	STC	7GA	16-16-16	9416	28	18.5	1.5	Time Drill		Dyna-Drill	402	1500	-	8.3	-	4-8-1/8	-	-	-	Bit, DD, Dynaflex, X-O, float, MSS, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 7-8" DC's, X-O, jars, X-O, 12 jts HWDP	Still not sidetracked?
RR#73	12-1/4"	STC	DSJ	Open	9329	42	5.0	8.4	5000	408	55	439	1000	-	8.3	-	8-2-1/8	-	-	-	Bit, bit sub, float, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 12 jts HWDP	Ream 8-3/4" hole, granite wore bit
81	12-1/4"	Sec	H-O	Open	9377	42	5.0	8.4	5000	408	55	439	1000	-	8.3	-	2-8-1/8	-	-	-	HO, X-O, float sub, 7-8" DC's, X-O, jars, X-O, 12 jts HWDP	Ream 8-3/4" hole
82	12-1/4"	STC	DST	Open	9385	8	1.5	5.3	5000	408	55	439	1000	-	8.3	-	8-8-1-1/2	-	-	-	Bit, XO, float sub, 7-8" DC's, X-O, jars, X-O, 12 jts HWDP	Drilling partially granite
83	12-1/4"	STC	Q9JL	Open	9501	115	17	6.8	30000	2449	50	455	1000	-	8.3	-	2-2-I	-	-	-	"	Finish drilling cement
84	12-1/4"	STC	DSJ	Open	9270	97	6.5	14.9	10000	816	60	415	1000	-	8.3	-	Metal in bit	-	-	-	Bit, junk basket, X-O, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	Pin from whipstock setting tool jammed in bit
RR#74	7-7/8"	STC	Core Bit		9277	7	1	7.0	8000	653	40	110	125	-	8.3	-	Stratapax chipped/good	-	-	-	Bit, core bbl, X-O, float sub, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	Jammed; looks hard; drills soft
85	12-1/4"	STC	SDGH	Open	9310	33	2	16.5	10000	816	60	415	1000	-	8.3	-	2-2-I	-	-	-	Bit, junk basket, X-O, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	Drill cement - pulled to attempt sidetrack
86	8-3/4"	STC	H-88	18-18-18	9396	86	16.5	5.2	Time Drill	-	Dyna-Drill	315	1050	-	8.3	-	2-5-1/8	-	-	-	Bit, DynaDrill, X-O, MSS, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	No sidetrack
RR#83	12-1/4"	STC	Q9JL	16-16-16	9435	39	25.0	1.6	5-10000	Avg 612	60	395	1200	-	8.3	-	3-4-I	-	-	-	Bit, float sub, 3 pt, X-O, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	18 hrs drilling 9432-9435 whipstock?
87	12-1/4"	STC	Q9JL	16-16-16	9439	4	21.5	0.2	10-30000	Avg 1633	60	403	1250	-	8.3	-	8-3-I	-	-	-	Bit, JB, 3 pt, X-O, 2-6-1/4" monel, 4-6-3/4" DC's, X-O, 6-8" DC's, X-O, jars, X-O, 12 jts HWDP	Nose pieces missing off of bit; may not be whipstock, may be junk
RR#85	12-1/4"	STC	SDGH	15-15-12	9441	2	3	0.7	10-20000	Avg 1224	60	381	1600	-	8.3	-	8-8-1/4	-	-	-	"	Nose pieces missing again; run mill
88	12-1/4"	STC	Q9JL	13-13-14	9452	8	10.5	0.8	5-10000	Avg 612	45-60	388	1200	Air Bit	8.3	-	3-2-I	-	10.5	-	Bit, X-O, 6-1/4" monel, jars, X-O, 12 jts HWDP	Drilling off whipstock; junk on bottom
RR#88	12-1/4"	STC	Q9JL	13-13-14	9461	9	5	1.8	10-15000	Avg 1020	60	395	1200	Air Bit	8.3	-	4-2-I	-	15.5	-	Bit, JB, X-O, 6-1/4" monel, jars, X-O, 12 jts HWDP	Finish drilling off whipstock
89	12-1/4"	STC	4JS	11-13-14	9558	97	13.5	7.2	45000	3673	45	337	1925	Air Bit	8.3	-	3-2-1/4	-	29.0	-	Bit, float sub, 3 pt, X-O, 2-6-1/4" monel, 2-6-3/4" DC's, X-O, 9-8" DC's, X-O, jars, X-O, 12 jts HWDP	Drilling granite; pulled to run down hole motor
90	12-1/4"	STC	Q9JL	16-16-16	9559	1	0.5	-	10000	8000	Dyna-Drill	325	1500	Air Bit	8.3	-	1-1-I	-	29.25	-	Bit, DynaDrill, (7-3/4"), float, 1-1/2° bent sub, 28" monel, 9-8" DC's, X-O, jars, X-O, 12 jts HWDP	Motor failed
91	12-1/4"	STC	Q9JL	16-16-16	9631	72	5.0	14.4	5-15000	1224	Dyna-Drill	325	1500	Air Bit	8.3	-	2-2-I	-	34.25	-	Bit, DynaDrill (7-3/4") float, 1-1/2° bent sub, 28" monel, 9-8" DC's, X-O, jars, X-O, 12 jts HWDP	Turn hole to right
92	12-1/4"	STC	F-4	13-13-13	9729	98	12.5	7.8	45000	3673		359	1900	-	8.3	-	-	-	46.75	-	Bit, float, 6 pt, monel, 9-8" DC, X-O, jars, X-O, 12 jts HWDP	Drilling granite
RR#90	12-1/4"	STC	Q9JL	24-24-24	9771	42	3.0	14.0	15000	1224		322	1500	-	8.3	-	-	-	49.75	-	Bit, DynaDrill, float, 2° bent sub, 1 monel, 9-8" DC, X-O, jars, X-O, HWDP	"
93	12-1/4"	STC	F-5	13-13-13	9883	112	16.0	7.0	50000	4082		351	1800	-	8.3	-	-	-	65.75	-	Bit, 3 pt, float, 1 monel, 9-8" DC, 1 X-O, jars, X-O, 12 jts HWDP	"
RR#93	12-1/4"	STC	F-5	13-13-13	9883	0	0	0	-	-		322	1500	-	8.3	-	-	-	65.75	-	Bit, 3 pt, float, 2 monels, 3 pt, 9-8" DC, 1 X-O, 1 jar, 1 X-O, 12 jts HWDP	Run multishots
RR#93	12-1/4"	STC	F-5	13-13-13	9884	1	0.25	4	40000	3265	45	344	1800	-	8.3	-	4-3-1/4	-	66.00	-	Bit, 3 pt, float, 2 monels, 3 pt, 9-8" DC, X-O, jars, X-O, 12 HWDP	Drilled one foot; granite; run multishot; strap in hole 9879.24', inspected BHA
94	12-1/4"	HTC	X-44	12-14-14	10082	198	29.5	67	45000	3673	60	351	1800	-	8.3	-	5-8-1/4	29.5	95.5	-	Bit, float, 6 pt, shock sub, 2 monels, 9-8" DC, X-O, jars, X-O, 12 HWDP	Drilling granite
95	12-1/4"	STC	F-5	13-13-14	10130	46	7.5	6.1	45000	3673	60	395	1800	-	8.3	-	2-2-I	37.0	102.5	-	Bit, 6 pt, float, shock sub, 1 monel, 9-8" DC, X-O, jars, X-O, 12 HWDP, 26 std DP, X-O, 3 pt, X-O	Drilling; TOH to retrieve part of survey tool
RR#95	12-1/4"	STC	F-5	13-13-14	10212	82	8.0	10.2	40000	3922	60	395	1800	-	8.3	-	5-3-1/4	51.0	116.5	-	Bit, 3 pt, float, shock sub, 1 monel, 9-8" DC, X-O, jars, XO, 12 HWDP, 26 stds DP, X-O, 3 pt, X-O	Drilling granite; strap in hole 10,111.69'
96	12-1/4"	HTC	J-44	12-14-14	10226	14	1.5	9.3	40000	3265	60	366	1500	-	8.3	-		1.5	118.0	-	Bit, 3 pt, float, shock sub, 1 monel, 9-8" DC, X-O, jars, X-O, 12 HWDP	Drilling granite; strap in hole 10,212.00'; left survey tool in hole
RR#96	12-1/4"	HTC	J-44	12-14-14	10226	0	-	-	-	-	-	344	1200	-	8.3	-	2-2-1/8	1.5	118.0	-	Bit, 3 pt, float, shock sub, 1 monel, 9-8" DC, X-O, jars, X-O, 12 HWDP	TIH after retrieving survey tool; came out laying down DP
RR#96	12-1/4"	HTC	J-44	12-14-14	10226	0	-	-	-	-	-	375	1300	-	8.3	-	2-2-1/8	-	0	-	Bit, float, 1 monel, 5-8" DC, X-O, jars, X-O, 15 HWDP	TIH, circ. survey 31-1/2° N74E TOH
97	12-1/4"	STC	Q9JL	24-24-24	10226	0	-	-	-	-	-	373	1500	-	8.3	-	2-2-1/8	-	0	-	Bit, turbodrill, 1-1/2° bent sub, 2 monels, 5-8" DC, X-O, jars, X-O, 15 HWDP	Drill granite; 2 Maurer Turbodrills plugged up
RR#96	12-1/4"	HTC	J-44	12-14-14	10226	0	-	-	-	-	-	329	1300	-	8.3	-	2-2-1/8	1	1	-	Bit, 3 pt, float, sub, shock sub, 2 monels, 5-8" DC, X-O, jars, X-O, 15 HWDP	TIH, ream 30' to btm circ. survey 31-1/2 ° N74E 10,176' (10,226 TD)
RR#97	12-1/4"	STC	Q9JL	24-24-24	10245	19	3	6.3	15000	1224	Turbo Drill	360	1850		8.3	-	2-5-1/4	-	1	-	Bit, turbodrill, 1-1/2° bent sub, 2 monels, 8-8" DC, X-O, jars, X-O, 15 HWDP	Drill granite
98	12-1/4"	SEC	GM88	12-12-15	10255	10	1.5	6.7	40000	3265	60	365	1500	-	8.3	-	2-2-1/16	-	2.5	-	Bit, 6 pt, float sub, 2 monels, 8-8" DC, X-O, jars, X-O, 15 HWDP	Ream and drill Kelly down
99	12-1/4"	STC	Q9JL	24-24-24	10352	97	3.5	27.7	10000	816	Turbo Drill	365	1900	-	8.3	-	3-4-1/4	-	2.5	-	Bit, turbo, float sub, bent sub, 2 monels, 8-8" DC, X-O, jars, X-O, 15 jts HWDP	Good run but wrong direction
100	12-1/4"	STC	F-5	12-12-14	10352	0	0	0	5-10000	-	60	365	1550	-	8.3	-	2-SE-1/16	-	8.5	28°N67E	Bit, float, 3 pt, 2 - 8" monels, 10-8" DC's, X-O, jars, X-O, 15 HWDP	Ream
RR#98	12-1/4"	Sec	GM88	12-12-15	10400	48	14	3.4	30000	2449	60	365	1500	-	8.3	-	2-6-1/4	-	30.0	28°N67E	Bit, 6 pt, S DC, 3 pt, X-O, 2 - 8" monels, 4-8" DC's, X-O, jars, X-O, 15 jts HWDP	"
101	12-1/4"	STC	Q9JL	24-24-26	10460	60	0	0	10000	816	Turbo Drill	329	1500	-	8.3	-	6-4-3/8	-	30.0	-	Bit, turbo, float sub, 2° bent sub, 2-8" monels, 7-8" DC's, X-O, jars, X-O, 15 jts HWDP	Turbine; run light for 2° bent sub
RR#100	12-1/4"	STC	F-5	12-12-14	10573	113	15-1/4	7.4	45	3673	60	375	1500	-	8.3	-	8-SE-1/4	-	45.25	30-3/4N57E	Bit, float, 3 pt, 2 - 8" monels, 7-8" DC's, X-O, jars, X-O, 15 jts HWDP	Good run; need more angle and left turn
102	12-1/4"	STC	F-5	12-12-14	10573	0	0	0	10	816	60	375	1500	-	8.3	-	1-1-1/8	-	52.25		Bit, 6 pt, short DC, float, 3 pt, X-O, 2 - 8" monels, 4-8" DC's, X-O, jars, X-O, 15 HWDP	Ream
103	12-1/4"	STC	F-5	24-24-24	10654	81	5-1/2	14.7	12	980	Turbo Drill	350	1800	-	8.3	-	4-7-1/4	-	52.25	33°N54E	Bit, turbine, float, bent sub, 2 - 8" monels, 7-8" DC's, X-O, jars, X-O, 15 HWDP	Good run
RR#102	12-1/4"	STC	F-5	12-12-14	10734	80	12	6.7	45	3673	45-60	375	1500	-	8.3	-	3-SE-1/8	-	64.25		Bit, float, 3 pt, shock sub, 2 - 8" monels, 7-8" DC's, X-O, jars, X-O, 15 HWDP	Didn't build; pull for motor
104	12-1/4"	STC	Q9JL	24-24-24	10791	57	4	14.3	10-12000	980	Turbo Drill	351	1700	-	8.3	-	3-5-1/4	-	64.25	34°N55E	Bit, turbine, float, 2° bent sub, 2 - 8" monels, 7-8" DC's, X-O, jars, X-O, 15 HWDP	1st run floats blew, filled pipe at 9700'; 2nd run good, filled pipe every 20 stds
105	9-7/8"	STC	Q9JL	12-12-12	10811	20	2.5	8	50	5063	45	410	1600	-	8.3	-	3-5-I	-	66.75		Bit, 3 pt, X-O, SDC, 3 pt, X-O, X-O, float sub, 2 monels, 7-8" DC's, X-O, jars, X-O, 15 HWDP	Reduce hole size, drilled 20'
106	8-3/4"	STC	7GA	11-11-13	11120	309	33	9	45000	5142	45-60	402	1600	-	8.3	-	5-7-1/4	-	99.75	34-1/4N55E	Bit (7GA), 6 pt w/float at btm, X-O, SDC, 3 pt, monel, 3 pt, monel, X-O, 11-6-3/4" DC, jars, X-O, 15 HWDP	Reduce hole size, took survey at 11,066'; cut wireline, TOH stuck pipe 43 stds out (keyseat)
RR#104	12-1/4"	STC	Q9JL	24-24-24	11120	0	0	0	-	-	-	-			8.3	-	3-5-1/4	-	0		Bit (12-1/4), bit sub, 2-8" DC, X-O, X-O, monel, X-O, jars, 15 HWDP	Clean out tight spot 6800' +
107	8-3/4"	STC	7GA	11-11-13	11454	334	26.5	12.6	45000	5143	60	388	1600	Air Bit	8.3	-	4-6-1/8	-	26.5	33-1/4°N50E	Bit (7GA), 6 pt, SDC, 3 pt, monel, 3 pt, monel, X-O, 11-6-3/4", X-O, Bowen jars, 15 HWDP	Drilling, TOH, LDDP for inspection
108	8-3/4"	HTC	HH-55	12-12-12	11595	141	10	14.1	50000	5714	60	388	1600	-	8.3	-	3-3-1/16	10	10	35-3/4°N50E	Bit (HH-55), 6 pt, X-O, shock sub, 2 monels, 3 pt, X-O, 11-6-3/4" DC, jars, X-O, 20 HWDP	Build assembly, built angle rapidly; drilling in altered zone, POH for packed assembly
109	8-3/4"	STC	4GA	11-11-11	11926	331	30	11.0	40000	4571	45	388	1600	-	8.3	-		40	40	35-3/4°N50E	Bit (4GA), 6 pt, shock sub, X-O, 3 pt, monel, 3 pt, monel, X-O, 8-6-3/4" DC, jars, 20 HWDP	Drill granite; POH for new bit
110	8-3/4"	STC	7GA	22-22-22	11951	25	2	12.5	10-12000	1371	Turbo Drill	262	2000	-	8.3	-	8-6-3/8	-	0	35-1/4°N53E	Bit, turbine w/float, float sub, 1-1/2° bent sub, X-O, 2-6-3/4" monels, X-O, 2-6-3/4" DC, X-O, hrs, 28 HWDP	Drill, turn hole to right, bit wore out
111	8-3/4"	Sec	H-88	11-11-11	11982	31	3	10.3	40000	4571	45	307	1850	-	8.3	-	2-8-I	-	4.5		Bit, 3 pt, float, X-O, monel, 3 pt, monel, 3 pt, X-O, 8-6-3/4" DC, jars, X-O, 28 HWDP	Ream, drill, stuck or high drag coming off bottom; jars not hitting
112	8-3/4"	STC	7GA	11-11-11	12079	97	11	8.8	45000	5142	40-45	404	1600	-	8.3	-	2-4-I	-	110.75	35°N54E	Bit, 3 pt, float, X-O, monel, 3 pt, monel, 3 pt, X-O, 8-6-3/4" DC, jars, X-O, 28 HWDP	Drill, sticking, TOH to work on mud and 40 DC
113	8-3/4"	STC	7GA	12-12-12	12100	21	1.5	19	45000	5142	45	440	1650	-	8.3	-	1-1-I	-	1.5	36°N53E	Bit, 3 pt, float, X-O, monel, 3 pt, monel, 3 pt, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	Drill, new mud, minimal drag, pull for motor
114	8-3/4"	Sec	H-88	Open	12123	23	1.5	15.3	5-8000	914	Turbo Drill	205	1700	-	8.3	-	8-6-1/4	-	1.5		Bit, turbine, float, 1-1/2° bent sub, X-O, 2 monels, 5-6-3/4" DC, jars, X-O, 37 HWDP	
115	8-3/4"	HTC	HH-77	22-22-22	12186	63	1.5	42	10-15000	1714	Turbo Drill	205	1700	-	8.3	-	4-4-1/8	-	1.5		Bit, turbine, float, 1-1/2° bent sub, X-O, 2 monels, 5-6-3/4" DC, jars, X-O, 37 HWDP	
RR113	8-3/4"	STC	7GA	12-12-12	12191	5	0.5	2.5	45000	5143	45	396	1600	-	8.3	-	2-2-I	-	6.5	35-1/2°N59E	Bit, 6 pt, X-O, 2 monels, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	
116	8-3/4"	HTC	HH-77	20-20-20	12310	119	3.5	34	15000	1714	Turbo Drill	228	1950	-	8.3	-	6-8-1/4	-	6.5		Bit, turbine, float, 1-1/2° bent sub, X-O, 2 monels, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	
RR113	8-3/4"	STC	7GA	12-12-12	12412	102	8	12.8	45000	5143	45	425	1900	-	8.3	-	4-4-1/8	-	17.5	36°N73°E	Bit, 6 pt, float, X-O, monel, 3 pt, monel, 3 pt, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	
117	8-3/4"	STC	7GA	12-12-12	12576	164	15.5	10.6	45000	5143	50-60	388	15-1700	-	8.3	-	2-4-I	-	36.5	37°N72°E	Bit, 6 pt, SDC, 3 pt, monel, 3 pt, monel, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	
118	8-3/4"	STC	7GA	12-12-12	12895	319	37	8.6	35000	4000	45	395	1750	-	8.3	-	3-5-I	-	75	37-1/4°N66E	Bit, 3 pt w/float, SDC, 3 pt, monel, 3 pt, monel, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	Drill, dropped angle
119	8-3/4"	HTC	HH-77	24-24-24	12961	66	2	33	7-12000	1371	Turbo Drill	220	1800	-	8.3	-	2-2-1/8	-	75		Bit, turbine w/float, float sub, 1-1/2° bent sub, X-O, 2 monels, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	
120	8-3/4"	Sec	H-88	Open	12961	0	0	-	-	-	Turbo Drill	-	-	-	8.3	-	pinched	-	75		Bit, turbine w/float, float sub, 1-1/2° bent sub, X-O, 2 monels, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	Bit pinched
121	8-3/4"	STC	7GA	Open	12961	0	0	-	-	-	Turbo Drill	220	1800	-	8.3	-	1-2-1/8	-	75		Bit, turbine w/float, float sub, 1-1/2° bent sub, X-O, 2 monel, X-O, 5-6-3/4" DC, jars, X-O, 37 HWDP	Eye tool won't work
RR121	8-3/4"	STC	7GA	12-12-12	13365	404	40	10.1	40000	4571	60	395	1800	-	8.3	-	4-4-1/4	-	115	36°N76°E	Bit, 3 pt, SDC, 3 pt, monel, 3 pt, monel, X-O, 5-6-3/4" DC's, jars, X-O, 37 jts HWDP	Drill granite, 40 pipe, p/u new string
122	8-3/4"	STC	7GA	Open	13365	0	0	0	-	-	Turbo Drill	220	1800	-	8.3	-	-	-	0		Bit, turbine w/float, float sub, 1-1/2° bent sub, X-O, 1 monel, X-O, 6-6-3/4" DC, jars, X-O, 31 HWDP	Wireline cratered, wo wireline motor failed
RR122	8-3/4"	STC	7GA	12-12-12	13365	0	0	0	-	-	60				-	-	-		-		Bit, 3 pt, SDC, 3 pt, 1 monel, 3 pt, X-O, 6-6-3/4" DC, jars, X-O, 30 HWDP	Twisted off, fishing
123	8-3/4"	STC	7GA	11-11-13	13365	0	Ream 3	0	-	-	60	402	1400	-	8.3	-	2-2-I	-	3		Bit, 3 pt, SDC, 3 pt, 1 monel, 3 pt, X-O, 6-6-3/4" DC, jars, X-O, 30 HWDP	Drill on junk, POH, run magnet
RR123	8-3/4"	STC	7GA	13-13-13	13365	0	" 3	0	-	-	60	402	1300	-	8.3	-	2-2-I	-	6		Bit, 3 pt, SDC, 3 pt, 1 monel, 3 pt, X-O, 6-6-3/4" DC, jars, X-O, 30 HWDP	Still junk after 2 magnet runs
124	8-3/4"	STC	V2HJ	Open	13338	8	2.5	3.2	30000	3429	55	381	1000	-	8.3	-	4-5-1/16	-	14		Bit, junk basket, float, X-O, monel, X-O, 6-6-3/4" DC, jars, X-O, 30 HWDP	Ran mill, 5 magnet runs, drill granite
RR123	8-3/4"	STC	7GA	13-13-13	13494	156	13	12	45000	5143	60	381	1300	-	8.3	-	2-4-1/16	-	27		Bit, 3 pt, SDC, 3 pt, 1 monel, 3 pt, X-O, 6-6-3/4 DC, jars, X-O, 30 HWDP	Drilling; pulled drill string apart during connection
125	8-3/4"	STC	7GA	11-11-11	13933	439	34.5	12.7	45000	5143	60	366	1600	-	8.3	-	8-8-3/8	-	34.5	36-1/2 N73	Bit, bit sub, X-O, 3-6-3/4 DC's, jars, X-O, 30 HWDP	Drill granite; bit cratered; TD - 13,933'
RR #8	12-1/4	STC	L4HJ	Open	10783	-	-	-	-	-	-	380	900		8.3	-	-	-	-		Bit, junk basket, junk basket, float sub, 3-6-3/4 DC's, jars, X-O, 30 HWDP	TIH to 10,783; circulated
126	8-1/2	STC	SD6H	16-16-16	11241	1234	23.5	52.5	10-15,000	1764	50	366	1350		8.3	-	4-8-I	-	-		Bit, junk basket, X-O, 15 HWDP, X-O, jars, X-O, 15 HWDP	TA6 7276, 7281, 10,023; drill out cement, DV tool, cement float
127	8-1/2	SEC	H-77	Open	13933	224	-	-	10-10,000	1176	-	424	1500		8.3	-	-	-	-			Clean out cement