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Issued: April 1982

Planning and Drilling Geothermal Energy Extraction Hole EE-2

**A Precisely Oriented and
Deviated Hole in Hot Granitic Rock**

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PLANNING AND DRILLING GEOTHERMAL ENERGY EXTRACTION HOLE EE-2
A Precisely Oriented and Deviated Hole in Hot Granitic Rock

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ABSTRACT

During the preceding work (Phase I) of the Hot Dry Rock (HDR) Geothermal Energy Project at Fenton Hill, two holes were drilled to a depth of nearly 3048 m (10 000 ft) and connected by a vertical hydraulic fracture. In this phase, water was pumped through the underground reservoir for approximately 417 days, producing an energy equivalent of 3 to 5 MW(t). Energy Extraction Hole No. 2 (EE-2) is the first of two deep holes that will be used in the Engineering-Resource Development System (Phase II) of the ongoing HDR Project of the Los Alamos National Laboratory. This phase of the work consists of drilling two parallel boreholes, inclined in their lower, open-hole sections at 35° to the vertical and separated by a vertical distance of 366 m (1200 ft) between the inclined parts of the drill holes. The holes will be connected by a series of vertical, hydraulically produced fractures in the Precambrian granitic rock complex. EE-2 was drilled to a depth of 4660 m (15 289 ft), where the bottom-hole temperature is approximately 320°C (608°F). Directional drilling techniques were used to control the azimuth and deviation of the hole. Upgrading of the temperature capability of existing hardware, and development of new equipment was necessary to complete the drilling of the hole in the extremely hot, hard, and abrasive granitic formation. This report describes the drilling history and the problems with bits, directional tools, tubular goods, cementing, and logging. A discussion of the problems and recommendations for overcoming them are also presented.

I. INTRODUCTION

The goal of the Los Alamos National Laboratory Hot Dry Rock (HDR) Geothermal Energy Project is to investigate and develop methods of extracting energy economically from hot rock within the Earth's crust. The objectives for accomplishing this are grouped into two phases: Research (Phase I) and Engineering-Resource Development (Phase II). During Phase I, water was circulated through a shallow pair of hydraulically fractured drill holes in an underground loop for approximately 417 days, providing an energy equivalent of 3 to 5 MW(t). This research phase, now completed, determined the feasibility of the HDR concept.

The engineering phase, now underway, will demonstrate the feasibility of long-term energy production from a Fenton Hill-type* HDR system. This phase consists of drilling two parallel boreholes that are inclined in their lower, open-hole sections at 35° to vertical and separated by a vertical distance of about 366 m (1200 ft). At depths below 3350 m (11 000 ft), the boreholes will be connected through the Precambrian rock complex by a series of parallel, vertical, hydraulically produced fractures broken through rock whose temperature ranges from 220°C (428°F) to 320°C (608°F) (Fig. 1). The objective of the Phase II system is to yield (through planned steps of fracturing, testing, and flow control) a convincing demonstration that a commercial-sized HDR reservoir can be formed, defined, and controlled in a technologically feasible manner. Equipment and techniques employed in Phase II are extensions and adaptations of commercial practice and hardware. It is anticipated that, with control of flow distribution among the fractures, a rate of heat extraction approximately 10 times more than that possible from the research phase system can be maintained for at least 10 yr with a power drawdown no greater than 10%. When this is accomplished, the Fenton Hill demonstration of a hydraulically fractured HDR heat-extraction system will have reached a successful conclusion.¹

The HDR demonstration project is located at Fenton Hill in the Jemez Mountains, which are part of a volcanic lineament that extends from Springerville, Arizona, to Raton, New Mexico (Fig. 2).² The Jemez Mountains also lie on the western margin of the Rio Grande rift, which is a major

*An HDR system located in crystalline granitic/metamorphic basement rock near a large volcanic heat source.

Fig. 1. Cross section of the Phase II system.

Fig. 2. Location of the Jemez Mountains relative to the Jemez Lineament and the Rio Grande Rift.

Continental geologic feature. The geology of the Jemez Mountains was first described by Renich³ and has since been described by Woods and Northrop,⁴ Smith et al.,⁵ Ross et al.,⁶ and Bailey et al.⁷ In general, the Jemez Mountains are characterized by many major volcanic events. Each event represents a separate cycle of volcanism; the oldest was approximately 10 000 000 yr ago, the youngest less than 100 000 yr ago. Because the formation of the Valles Caldera occurred only about 1 000 000 yr ago, a large amount of heat is still retained in rocks underlying the entire area within a few kilometers of the surface.

The Fenton Hill HDR site is located on the western flank of the Jemez Mountains, 50 km (30 miles) west of Los Alamos (Fig. 3). This location was selected because of its (1) high local geothermal gradient, (2) absence of local faulting, (3) accessibility to the highway and nearby power lines, (4) location within U.S. Forest Service land, and (5) location in an area that was

Fig. 3. Location of the Fenton Hill site in northern New Mexico.

burned during a 1972 forest fire (Fig. 4). Thus, the combination of a near-surface and large heat source plus the site location near Los Alamos, made Fenton Hill an appropriate choice for research and development of a commercial size HDR geothermal project.

This report presents a chronological history of the work done and the problems encountered in planning, drilling, casing, cementing, and logging precisely oriented and deviated holes in hot, abrasive, crystalline rock. The last section of this report presents a short discussion of those problems and includes recommendations regarding future applications.

II. SUMMARY OF PRECEDING WORK

Geothermal Test Hole No. 2 (GT-2) was the first deep exploratory hole of the Phase I reservoir, the research phase, drilled at Fenton Hill. Drilling began on February 17, 1974, and was completed to a temporary depth of 2042 m (6701.5 ft)* in September 1974. The hole was cased with 27.3-cm (10-3/4-in.) casing from the surface to 773 m (2535 ft), which is 40 m (131 ft) into the Precambrian granitic basement rock.

A series of hydraulic fracturing tests, conducted at specific depths in the granitic section of the hole, was completed in early October 1974. GT-2 was then deepened to 2932 m (9619 ft) and various diagnostic logging operations were performed. A 185-m (608-ft) liner assembly, with a polished-bore receptacle on the upper end, was then placed and cemented in the bottom

*All depths in this report were measured from the top of the Kelly Bushing (KB) of the drill rig that drilled the hole. This bushing is generally about 8 m (25 ft) above the ground surface.

Fig. 4. HDR geothermal site at Fenton Hill, looking northwest.

section of the hole. Detailed accounts of the planning, drilling, logging, and testing work performed in GT-2 are described in previous reports.⁸⁻¹⁴

Energy Extraction Hole No. 1 (EE-1) was the second deep exploratory hole drilled at Fenton Hill. Drilling for EE-1 began in May 1975 and continued until October 1975, when the total depth of 3064 m (10 053 ft) was reached. The hole was cased to 2930 m (9600 ft).¹⁵

A small flow connection between GT-2 and EE-1 was produced by hydraulic fracturing, but was not considered to be adequate communication for reservoir experimentation.

Directional drilling in GT-2 was instituted in 1977 at approximately 2500 m (8200 ft) to produce a low-impedance flow path between GT-2 and EE-1. The drilling of the new hole, GT-2A, was not successful in that a satisfactory connection to the fracture emanating from EE-1 was not made. The lower part of GT-2A was cemented and in May 1977, GT-2B was sidetracked out of it at approximately 2530 m (8400 ft). An acceptable communication between GT-2B and

EE-1 was accomplished at the GT-2B/fracture intersection at 2673 m (8769 ft).¹⁶ See Fig. 5 for a cross-sectional view of the Phase I system.

Five circulation experiments (Run Segments 1-5) were conducted in the Phase I system between June 1977 and December 1980, lasting for a combined total of 417 days. During this time, pressurized water, which had been heated by passing through the underground fracture system, was circulated through surface heat exchangers, producing 3 to 5 MW(t), with the heat being wasted to the atmosphere. Electrical energy was produced during Run Segment 5 by a 60-kW binary-fluid turbine generator.

III. DRILLING PLAN

A detailed drilling program for Hole EE-2 was prepared by Grace, Shursen, Moore, and Associates (GSM) of Amarillo, Texas,¹⁷ and was submitted to the Los Alamos National Laboratory on October 1, 1978.

The drilling plan for EE-2 specified drilling to an anticipated temperature of 275°C (525°F) at approximately 4300 m (14 000 ft). This depth was based on the thermal gradient measured in the existing boreholes, GT-2 and EE-1, at Fenton Hill. The EE-2 borehole design specified the hole to be substantially vertical from the surface to approximately 2916 m (9568 ft). Below that depth, the borehole was to be directionally drilled at an angle of 30° from vertical to 4267 m (14 000 ft). The GSM drilling plan gave detailed specifications on all aspects of the drilling program, including bits, hydraulics, tubular goods, drilling fluids, assemblies,

Fig. 5. Cross section of the Phase I system.

pressure control equipment, and wellhead sketches. An outline of the program is shown in Appendix A.

IV. EE-2 DRILLING HISTORY

A. Contractural Agreements

The major contracts that were issued to perform the work associated with the drilling of EE-2 are listed below.

1. Major Drilling Contract. Because of the large increase in drilling activity in the Rocky Mountain area, it was expected that obtaining a drilling rig would be difficult. Consequently, bids were solicited by the U.S. Department of Energy from over 30 contractors. Three bids were received and the drilling contract was placed with the Brinkerhoff/Signal Drilling Company, a division of Petrolane Corporation, for their Rig No. 56. Mobilization of the rig at the Fenton Hill site began March 26; drilling started April 3, 1979.

An inventory of the Brinkerhoff/Signal Rig No. 56 equipment is included in Appendix B.

a. Contract Items. The contract with Brinkerhoff-Signal Drilling Company contained five major items: mobilization, hourly operations with drill pipe and without drill pipe, standby secured with crew and without crew, demobilization, and subcontractor-acquired property and services.

b. Third-Party Contracts. The contract item for subcontractor-acquired property and services (special items and services) provided for procurement of reimbursable items and services under a third-party agreement. Typical services that were furnished to the drilling contractor under this item included cementing, casing setting, bits, underreamers, logging, orienting services, and directional-drilling equipment.

Other items of significant importance are listed as:

(1) Downhole (Positive Displacement) Motors. Three makes of downhole motors were used: Smith Dyna-Drill, Christensen Navidrill, and Baker Motor. These motors were adapted for high-temperature use, but were generally limited to depths of less than 3000 m (10 000 ft) and temperatures less than 200°C (400°F).

(2) Directional Drilling Engineer. Directional drilling services were provided by Eastman-Whipstock.

(3) Steering Devices and Surveying Tools. Magnetic single-shot surveys (Eastman-Whipstock) and magnetic multi-shot surveys (Sperry-Sun) were

used to check hole direction during rotary drilling. While drilling with the turbodrills, steering devices by Eastman-Whipstock and Sperry-Sun were used, but the high temperatures caused their early failure. Scientific Drilling Control's "Eye" tool proved to be adequate and was used extensively.

(4) Shock Absorbers. At temperatures less than 200°C (400°F), Drilco shock tools were successfully used; at higher temperatures, shock absorbers made by Houston Engineering Inc. were used.

(5) Drilling and Fishing Jars. Hydraulic drilling jars (HYDRA-JAR) were modified by Houston Engineering to operate successfully at temperatures to 290°C (550°F). For fishing operations, Bowen Tool Type J mechanical jars were used.

(6) Drill Bits. The major suppliers for tungsten carbide insert (TCI) bits were Smith International and Security, although Reed Tool Company and Hughes Tool Company (HTC) bits were also used.

(7) Coring Bits. Stratapax coring bits manufactured especially for use in EE-2 by Smith Tool Company (STC) were used exclusively.

2. Consultant Services

a. Drilling Manager. Because of the complexity of the operations anticipated in drilling deep, hot, deviated holes, the services of a drilling manager were required. A purchase order contract was awarded to GSM to furnish these services. The contract provided for continuous on-site supervision by experienced drilling engineers, who were to direct the operation of the drilling rig and crews and to coordinate these drilling-related activities with numerous Los Alamos-directed activities. Usually two drilling engineers were available at the site on a rotating basis, and at times a third engineer was available for relief duty.

3. Turbodrills. High-temperature turbodrills were developed as a joint effort between Los Alamos and Maurer Engineering, Inc. (MEI), of Houston, Texas. Two 19.7-cm (7-3/4-in.) turbodrills were purchased for use at Fenton Hill, with maintenance for the turbodrills provided under the third-party clause of the drilling contract.

4. Road and Site Maintenance. A contract was let to C.J.C., Inc., General Contractors, Jemez Springs, New Mexico, to provide necessary site maintenance, supply water for drilling operations, remove and repair fences, and maintain the reserve pond.

B. Drilling Progress¹⁸

1. Mobilization. On March 26, 1979, Brinkerhoff-Signal Drilling Company began moving equipment for Drilling Rig No. 56 onto Fenton Hill. The substructure was in place March 31, and the rig was erected April 4 (Fig. 6).

The contractor employed four drilling crews, each consisting of a driller, a derrickman and three floormen. Drilling progressed 7 days/wk, 24 h/day. Each crew worked an 8-h shift for 6 days, then had 2 days off and returned to work on the shift preceding the one that they had previously worked.

One tool pusher, who lived on location, was employed by Brinkerhoff-Signal; drilling managers employed by GSM under contract to the Laboratory* also lived on site. Engineering personnel, employed in the Laboratory's Geosciences Division, rotated on a 24-h basis so that the Laboratory was always represented on site to monitor all drilling-related activities.

The elevation of the top of the KB was 2657.8 m (8719.8 ft) above mean sea level, and all depths in this report were measured from that point. A summary of the EE-2 drilling history is shown in Fig. 7; a breakdown of time utilization for drilling activities is illustrated in Fig. 8.

2. Volcanic Rock. At 8:30 am, on April 4, drilling began in the Bandelier volcanic tuff below the previously placed conductor pipe, using a 66-cm (26-in.) HTC OSC3AJ tooth bit. Drilling through the tuff presented no problems and was completed in two days. The average penetration rate varied from 3 to 8 m/h (10 to 24 ft/h). For bit specifications and use record, see Appendix C.

3. Sedimentary Rocks. The Abo Formation (Permian red beds) was encountered at a depth of 140 m (460 ft) on April 6. Drilling with the same bit continued to a depth of 184 m (604 ft), at which time a STC DTJ (Bit No. 2) was run in. The deviation from vertical gradually increased from 0.5° to 5° at 286 m (938 ft), despite "fanning" at a low bit load of 4.5 Mg (10 000 lbs), and a high rotational speed of 150 rpm. A "pendulum effect" assembly was then used consisting of the bit and shock sub, two 20-cm (8-in.) drill collars, a stabilizer, another drill collar, and a stabilizer. Drilling with this assembly at loads of 111 205 to 133 446 N (25 000 to 30 000 lbs) and 90 to 95 rpm brought the hole back to 1-1/2° from

*Los Alamos National Laboratory, hereafter referred to as the "Laboratory."

Fig. 6. Raising the Brinkerhoff-Signal Rig No. 56 in a snowstorm on April 5, 1979.

vertical at a depth of 409 m (1342 ft). The average penetration rate in the Abo Formation varied from 1 to 3 m/h (3 to 10 ft/h) with bit weights of 4.5 to 11.3 Mg (10 000 to 25 000 lbs).

The Madera Formation (Pennsylvanian shales and limestones) was penetrated on April 14 at a depth of 381 m (1250 ft). Drilling continued using the HTC OSC3AJ and STC DTJ bits to a depth of 544 m (1785 ft). Interbedded limestones and sandy clay/shale units, ranging in thickness from 1.5 to 8 m (5 to 25 ft), were encountered throughout the Madera. The maximum bit weight that could be applied in the softer formations without the bit balling up was 111 205 N (30 000 lbs). Penetration rates in the Madera Formation ranged from 2 to 5 m/h (6 to 15 ft/h), at rotational speeds up to 110 rpm.

Total circulation was lost in a coarse, unconsolidated quartz sand layer at 316 m (1038 ft), but was regained by the addition of cottonseed hulls. The

Fig. 8. Percentage breakdown of drilling activities.

50.8-cm (20-in.)-diam casing was started in the hole on April 18, but mismatches between casing and coupling threads delayed the completion of run-in until April 20. The bottom of the casing was landed at a depth of 543 m (1780 ft), and then cemented to the surface. Casing details and cementing procedures are described in Sec. IX and X.

Drilling out of the cement began on April 22 with a 44.5-cm (17-1/2-in.) Security S4T bit (Bit No. 5), and continued in the Madera Formation at 3 to 4 m/h (10 to 12 ft/h), with 9 to 18.1 Mg (20 000 to 40 000 lbs) weight. Approximately 15 bbls of mud were lost between 574-576 m (1883-1890 ft), but the zone sealed off as drilling progressed. While drilling through this interval, the circulating fluid carried 19 kg/m³ (30 lbs/bbl) lost circulation

material (LCM). Drilling continued steadily at 2.5 to 3 m/h (8 to 10 ft/h) until circulation was lost again at 717 m (2354 ft) on April 26.

This lost circulation zone (LCZ), a cavernous limestone section overlying the granite, had been anticipated from the experience in the preceding holes, and the drilling plan provided for an appropriate course of action. Water trucks were immediately alerted to start hauling water as preparations were made to continue drilling without returns. Penetration into the cavernous limestone section progressed rapidly, despite trouble with the stabilizers becoming balled up with clay. The surface of the granitic basement was encountered at 732 m (2402 ft). The lithology of the sedimentary section of EE-2 is illustrated in Plates 1 and 2 (located in pocket on inside back cover).

4. Granitic Basement Complex. Drilling in the granitic rock continued with a Security S-88 bit (No. 7) at a rate of 2 to 4 m/h (7 to 12 ft/h) at 22.6 to 24.9 Mg (50 000 to 55 000 lbs). At 790 m (2593 ft), drilling was halted because excessive pipe drag indicated tight spots/squeezing zones at the top of the granite. A cement plug was planned to stabilize that section. The hole below 734 m (2407 ft) was filled with high-viscosity mud, the drill pipe run in open-ended to 734 m (2407 ft), and 200 sacks of a Class H neat cement mixture were pumped in.

On April 29, while tripping in hole to drill out the plug, an obstruction was encountered at 629 m (2063 ft). Reaming/drilling/washing progressed to 648 m (2127 ft), but no progress was made until a high-viscosity mud was used to stabilize the hole. Reaming then continued to total depth, 790 m (2593 ft), but no cement was encountered at the top of the granite. Problems with the caving-hole condition at about 732 m (2400 ft) required that another cement plug be placed before the 34-cm (13-3/8-in.) casing could be set. Accordingly, 300 sacks of Class H cement were placed through open-ended drill pipe on top of a wad of burlap bags set at 747 m (2450 ft).

When the hole was re-entered the following day, additional bridges were encountered below 680 m (2230 ft), but little or no cement was found. The hole was conditioned with high-viscosity mud and the 34-cm (13-3/8-in.) casing was started in the hole. A "Texas" shoe was installed in place of the guide shoe, and a casing power swivel was ordered out because trouble was anticipated getting the casing in. However, because of bridges in the hole, the casing could only be run in to approximately 689 m (2260 ft). It was withdrawn and the hole reamed again.

The next attempt to insert the casing to the full desired depth of 790 m (2593 ft) on May 3 was unsuccessful. Instead, it was set 30 m (100 ft) higher, at 760 m (2493 ft), 27 m (90 ft) in the granite and thus considered sufficient.

The cementing of the casing was designed to be done in two stages (see Section IX, Casing). The first stage cementing began at 10:00 pm on May 3, but it appeared that the top plug ruptured on reaching the float collar, and the displacement water above the plug flushed the cement into the LCZ above the granitic contact. Recementing of the first stage was completed on May 5 by setting a Halliburton retainer inside the 34-cm (13-3/8-in.) casing at 735 m (2410 ft) and pumping 300 sacks of Class H cement with 40% silica flour down the drill pipe through the retainer.

The second stage was cemented through a Halliburton full opening (F0) external packer stage collar located at 544 m (1785 ft) in the 34-cm (13-3/8-in.) casing above the bottom of the 51-cm (20-in.) surface casing. After the first stage cement had been set, Halliburton cemented the second stage to the surface with 1000 sacks of 50/50 Pozmix Class A cement with 40% silica flour.

When the hole was re-entered on May 7 with a HTC J77, 31-cm (12-1/4-in.) bit (No. 10), the top of the cement was encountered at 530 m (1740 ft), above the F0 cementing collar. Drilling continued through the cement plugs, retainers and wiper plugs to 795 m (2610 ft). Shortly after midnight on May 9, a sudden high torque indicated a bit problem. When the bit was pulled (Bit No. 11), it was found that the inner sections of all three cones were missing.

A fishing magnet was ordered from Farmington, New Mexico, and run in, but the 28.6-cm (11-1/4-in.)-diam magnet would not pass an apparent obstruction at approximately 728 m (2390 ft). Bit No. 10 was rerun to ream through the obstruction. After reaming down through the obstruction for several hours, lost circulation occurred. The reaming assembly was pulled and a smaller diameter magnet, 25.4 cm (10 in.), was run in; but the 22.9-cm (9-in.)-diam drill collars above the magnet would not go through the obstruction. A Laboratory temperature survey indicated that the fluid loss was occurring through the casing at a depth of approximately 731 m (2400 ft) near the top of the granitic contact.

A 30.8-cm (12-1/8-in.)-diam swage with jars was run in to work open the restriction in the casing. Tight spots were encountered at 725 m (2380 ft)

and 737 m (2420 ft). A casing roller was then run in with very little resistance to 751 m (2465 ft).

A series of logs run by Schlumberger on May 11 indicated breaks in the casing between 722 to 728 m (2370 to 2390 ft) and 742 to 752 m (2434 to 2468 ft). During the next 3 days, additional surveys were made with the Laboratory temperature and spinner tools, a McCullough casing inspection log, and Birdwell's cement bond and collar locator tools.

From the logging surveys, it appeared that the casing shoe was at 793 m (2602 ft), buckled casing occurred at 756 m (2480 ft), and a gap or break occurred at 732 m (2403 ft). Damaged casing existed between 725 and 732 m (2378 and 2403 ft). Water exited the casing at 725 m (2380 ft) and flowed upward outside the casing into the cavern between 717 and 719 m (2354 and 2360 ft) (Fig. 9).

The plan formulated to deal with this situation consisted of (a) leave the bottom section, below 725 m (2380 ft), and (b) seal off the LCZ by cementing the break in the casing at 725 m (2380 ft). Accordingly, Dowell was ordered out of Farmington on May 16, three joints of open-ended drill pipe were run in to clear the blow-out preventor (BOP) and 400 sacks Dowell plaster of Paris gypsum cement (RFC) were pumped down the hole, followed by 1000 sacks of Class H cement with 40% silica sand, displaced by 44 bbls of water to effect a hydrostatic pressure squeeze on the slurry in the hole.

The cement was tagged at 545 m (1788 ft) and drilling with a steel-toothed bit, Security S3S (Bit No. 12), began with full-circulation returns. An obstruction was encountered at 725 m (2380 ft), and during reaming, metal flakes appeared in the returns. These were thought to originate from the top of the parted casing. Two trips in the hole with a magnet and a junk basket recovered 5.4 kg (12 lbs) of metal junk. Two more trips the next day with a magnet recovered 8.2 kg (18 lbs) metal junk. Drilling began again at 733 m (2405 ft) with a 31-cm (12-1/4-in.)-diam STC DTJ (Bit No. 13). Lost circulation (30%) occurred almost immediately but was reduced to 10% when 350 bbls of LCM consisting of gel, wood chips, and cottonseed hulls were pumped downhole. The next day, circulation with full returns was back. Bit No. 13, when pulled out of the hole, had "flats" on all three cones, and approximately 5.4 kg (12 lbs) metal cuttings were found in the junk basket. A tight section of casing was then milled from 725 m (2380 ft) to 735 m (2412 ft). Bit No. 14 (STC DTJ) reached granite at 737 m (2421 ft). Lost

Fig. 9. Diagram illustrating damaged casing section between 756 m (2480 ft) and 722 m (2370 ft).

circulation occurred while cleaning the hole below 737 m (2420 ft) and was restored twice with the addition of LCM while drilling at 749 m (2456 ft). Circulation was lost again; a Laboratory temperature log indicated that water was exiting through the damaged casing at approximately 726 m (2382 ft).

Dowell was then called in to cement the zone with 300 sacks of Class H neat cement, followed by 14 bbls of water. The next day, the cement was drilled out to 737 m (2417 ft) with full returns.

Drilling continued to a new depth of 793 m (2602 ft) when complete lost circulation recurred. A 100 bbl pill of high-viscosity LCM was pumped through open-ended pipe at 465 m (1525 ft) followed by 600 sacks of Class H cement. Drilling was resumed with Bit No. 16, but circulation was lost at 805 m (2641 ft). A massive cementing-squeeze

plan was implemented to plug the 1.8- to 2.4-m (6- to 8-ft) high cavern on top of the Precambrian contact at 732 m (2402 ft). Dowell pumped in 200 sacks RFC, 1000 sacks Class H neat cement and 1000 sacks Class H cement with 40% silica flour. Bit No. 17, steel-toothed Security 31-cm (12-1/4-in.) -diam H-100, drilled out the cement from 414 to 729 m (1360 to 2393 ft) with full returns. For the next 16 days, 518 m (1699 ft) of new hole in granite was drilled.

On June 17, while drilling at 1323 m (4340 ft), the drilling fluid pressure dropped from 1800 psi to 1500 psi, suggesting a drill stem washout.

While pulling out of the hole, the drill string parted, dropping three joints of drill pipe and the bottom-hole assembly (BHA) approximately 244 m (800 ft) to the bottom of the hole. HOMCO of Farmington, New Mexico, was called immediately for fishing services, and the pipe was retrieved the same day.

On June 19, after very rough drilling for 8 h with essentially no penetration, the bit (No. 26) was pulled for examination. Two 30.4-cm (12-in.) long blades were discovered missing from one of the bottom-hole stabilizers (RWP) on the BHA. After two fishing attempts with the HOMCO magnet, one of the blades was recovered. The third run recovered several pounds of metal cuttings, but the following two fishing trips produced nothing. An STC Q9JL bit (No. 27) was run in to drill up the remaining junk. The badly worn ends of the missing stabilizer blade were found in the junk basket. The central piece was recovered by a magnet during the next run.

The following day, June 22, while drilling at 1329 m (4362 ft), complete lost circulation again occurred. A Laboratory temperature survey indicated the LCZ to be between 549 and 731 m (1800 and 2400 ft). Dowell was called to the site and a RTTF (Halliburton) packer was set on drill pipe at 460 m (1508 ft) and the annulus filled with water. Dowell pumped in 200 sacks RFC followed by 500 sacks Class H neat cement. Drilling resumed on June 25 with Bit No. 28 (Smith F-9) with full returns to the surface.

On June 28, the first Maurer turbodrill run drilled 17 m (57 ft) of new hole, from 1480 to 1497 m (4855 to 4912 ft) with a Security H-100 bit (No. 31). After rotary drilling had deepened the hole an additional 30 m (100 ft), a drop in the drilling fluid pressure indicated a possible washout. When the BHA was pulled, it was found that the Mustang shock absorber had failed and had developed considerable wobble. At 1484-m (4870-ft) depth, the deviation had gradually increased to 6°, but by 1522 m (4995 ft) the deviation had jumped to 8° -- probably due to the failed shock absorber. On June 30, the BHA parted at 1509 m (4950 ft) leaving in the hole a 31-cm (12-1/4-in.) STC F-9 bit, six-point roller reamer, short drill collar, stabilizer, 20.3-cm (8-in.) drill collar, stabilizer crossover, and five 22.9-cm (9-in.) drill collars. Fishing the next day by HOMCO was successful and revealed that the parted BHA did not drop to the bottom, and the bit, No. 33, was undamaged.

Steady drilling, with only minor problems, increased the hole depth from 1528 m (5012 ft) to 1979 m (6492 ft) over the next seven days.

Beginning on July 8, directional drilling equipment was employed at a depth of 1979 m (6492 ft) to change the hole to the required NE direction. At that depth, the deviation was $5\text{--}1\frac{1}{2}^{\circ}$ from the vertical, with a direction of S77W. The Dyna Drill motor and the Baker motor proved to be quite successful at this range of temperature and depth. (See Section VIII for history of the drilling motor operations.) Between motor runs, the hole required reaming and was also drilled with rotary tools using a stiff BHA to maintain the required direction.

By July 15, drilling motor runs had increased the hole to 2065 m (6775 ft), with a $4\text{--}3\frac{1}{4}^{\circ}$, N37W deviation, representing a 40° direction change. During the first of the motor runs, an Eastman-Whipstock Directional Orientation Tool (DOT) was used with a McCullough wireline to control the direction. The DOT was plagued by intermittent signal losses, which was partially attributed to wireline malfunction. (A history of the DOT and the steering tools is included in Section VIII on directional drilling.) Surveys of the hole direction were largely accomplished by Eastman Whipstock single shot tools, which were run in the hole every 20 to 30 m (60 to 90 ft).

Another Baker motor run increased the depth to 2178 m (7146 ft) and changed the direction to $5\text{--}1\frac{1}{2}^{\circ}$, N40E by July 18. For the next five days, an angle-building rotary BHA [bit, six-point reamer, 9-m (30-ft) monel collar, two 20.3-cm (8-in.) drill collars, one RWP stabilizer, two 20.3-cm (8-in.) drill collars, one RWP stabilizer, 18 each 20.3-cm (8-in.) drill collars] was used to make an additional 311 m (1022 ft) of hole for a depth of 2490 m (8168 ft). The angle of deviation was built at the rate of about 1.5° per 30 m (100 ft), but the hole tended to walk back to the north (from N40E to N17E). Accordingly, another Dyna Drill run was attempted, but the motor failed after drilling 7 m (22 ft), at a temperature of 140°C . At this depth, the performance of the drilling motors was drastically decreased by the high temperature, and the Maurer turbodrill was used exclusively to control the hole direction from that time. Drilling with the turbodrill continued throughout the month of August and into September, interrupted by reaming runs and numerous small washouts at the drill pipe tool joints.

On August 23, at a depth of 2853 m (9362 ft) and a direction of $14\text{--}1\frac{1}{4}^{\circ}$, N41E, the DOT tool and operating personnel were released after weeks of intermittent operation. Sperry Sun "Hadies" direction rotation tools were tried next day, but three tools failed in succession at about 2743 m (9000

ft). Scientific Drilling Control's "Eye" tool was ordered out and it performed satisfactorily for the remainder of the directional drilling. The deviation (based on the Eye tool) was increased from 12° to 16.3° and turned from N42E at 2972 m (9750 ft) to N59°E at 3023 m (9917 ft) by September 11.

On September 12, lost circulation occurred while reaming near the bottom and the drill pipe was immediately pulled out of the hole. A temperature survey indicated the LCZ to be between 549 m and 610 m (1800 ft to 2000 ft). A Birdwell caliper log taken on September 13, revealed a break in the 34-cm (13-3/8-in.) casing at approximately 549 m (1800 ft). Dowell pumped in 200 sacks Class H cement with 12-1/2% Gilsonite, and 1/4% of Celloflake through 5 stands of open-ended pipe. Half an hour later, 400 more sacks of Class H neat cement were pumped down the hole. The cement was later tagged at 421 m (1380 ft), and drilled through at 568 m (1865 ft). It was estimated that approximately 254 sacks of cement were drilled out of the casing and that 346 sacks went into the formation. On September 15, the hole was reamed to the total depth of 3068 m (10 067 ft). Drilling was halted because of indications of a plugged bit. While trying to clear the plug, the drill pipe parted at 1386 m (4549 ft). Dia-Log was called out for free-point determination and break-out service. After several attempts, the drill string was unscrewed at 1984 m (6510 ft) and fished out of the hole. Another backoff was made, which freed the drill stem above 2930 m (9612 ft).

Eighteen days of fishing followed, which included losing 2438 m (8000 ft) of Dia-Log wireline in the hole, attempting to retrieve it with a spaghetti pipe service, breaking the spaghetti pipe downhole, having to fish out spaghetti pipe fishing tools, and then having drill pipe break in the hole several more times. At last the stuck BHA was finally removed on October 6 using Dailey jars set for 400 338 N (90 000 lbs).

Rotary drilling resumed on October 7 with Bit No. 77, an STC SJS bit, and a 123-m (403-ft)-long building assembly consisting of three-point roller reamer, float sub, monel collar, 20.3-cm (8-in.) drill collar, six-point roller reamer, 20.3-cm (8-in.) drill collar, three-point roller reamer, and nine each 20.3-cm (8-in.) drill collars. After drilling 111 m (366 ft) of new hole and building the angle from 16° to $17-3/4^{\circ}$ at a direction of N77°E, the angle decreased to $17-1/2^{\circ}$ on October 11. The Maurer turbodrill, with the Scientific Drilling Control's "Eye" tool, was used to increase the inclination to 20° at a depth of 3216 m (10 552 ft) while still holding approximately the

same direction. After reaming, rotary drilling was again resumed on October 14 with a more limber BHA, replacing the 20.3-cm (8-in.) drill collars with 16.8-cm (6-5/8-in.) drill collars and using a Reed FP63J bit (No. 80). Over the next 24 days, rotary drilling progressed to a depth of 3528 m (11 576 ft) with a variety of 31.1-cm (12-1/4-in.) bits. During this time, a considerable number of wireline failures occurred in running the Eastman single shot tool, which necessitated using the heavier 1.6-cm (5/8-in.) rig sand line. The angle had been building to 34-1/2° at this time, but the hole had walked left again, to a bearing of N54°E. Typical building assemblies consisted of a bit, three-point roller reamer, float sub, 17.1-cm (6-3/4-in.) monel collar, 17.1-cm (6-3/4-in.) drill collars (with occasionally other three-point roller reamers), and Hevi-Wate drill pipe (HWDP). On November 7, plans to reduce the EE-2 hole size to 22.2 cm (8-3/4 in.) were initiated. A 28-cm (11-in.) hole was drilled from 3528 m to 3534 m (11 576 to 11 596 ft). Below that, a 24.4-cm (9-5/8-in.) Security H10J bit (No. 93) was tripped in and taken to 3540 m (11 616 ft). On November 10, the first EE-2 coring run occurred. Approximately 1.2 m (4 ft) of core was obtained between 3576 m (11 734 ft) and 3579 m (11 743 ft) (Fig. 10), using a newly developed STC combination Stratapax and roller cone core bit (see Section VII).

Drilling continued with 22.2-cm (8-3/4-in.) bits for the next nine days, interrupted by frequent on-bottom milling and magnet operations that resulted from pieces of the 34-cm (13-3/8-in.) casing failing downhole, and retrieving lost cones. A survey at 3721 m (12 208 ft) indicated 35°, N59°E. The second coring run occurred on November 20, from 3739 m (12 266 ft) to 3741 m (12 275 ft), but no core was recovered. Five days later, the third coring run, from 3916 m (12 848 ft) to 3918 m (12 856 ft), resulted in 2.4 m (8 ft) of core (Fig. 11). Drilling with 22.2 cm (8-3/4-in.) bits continued for the next 11 days, with considerable reaming and working of the string necessary to keep the pull force below 1 779 280 N (400 000 lbs).

On December 2, approximately 133 446 N (30 000 lbs) of drill collars were removed from the BHA to reduce downhole torque. The new BHA consisted of a bit, junk basket, six-point roller reamer, three-point roller, reamer, short drill collar, three-point roller reamer, monel collar, three-point roller reamer, nine joints HWDP, jar, and two joints HWDP.

Fig. 10. Core Run No. 1: 1.2 m (4 ft) long taken from between 3576 to 3578 m (11 734 to 11 743 ft).

Beginning at this time, hole drag was reduced by the addition of Baroid Torq-Trim II to the circulating fluid. Additions were made at the rate of approximately 125 gallons per day throughout the remainder of the drilling.

Fig. 11. Core Run No. 3: 2.4 m (8 ft).

On December 8, the fourth core was cut (Fig. 12) from 4100 m (13 454 ft) to 4103 m (13 464 ft) and consisted of a 134.6-cm (53-in.) recovery. As drilling ahead continued, considerable difficulty was encountered with a number of successive single-shot survey runs that resulted in no picture or in the tool stuck within the pipe (see Section XIII). Drilling was suspended at a depth of 4162 m (13 657 ft) on December 12, to conduct extensive reaming operations to try to reduce hole drag. A reamer assembly, consisting of a bit and string reamer, was run in to ream out doglegs at 929 m, 2011 m, and 2103 m (3050 ft, 6600 ft, and 6900 ft). During this time, Tuboscope Inspection Service was called out to inspect the drill string. Also, hard banding of the tool joints was performed by Basin Tool Company (see Section XII).

Drilling ahead continued on December 20 to a depth of 4253 m (13 955 ft), and when the bit (No. 117) was pulled, it had drilled 91 m (299 ft) in 22 h. The deviation was 35°, with a direction of N74E.

On December 20th, the fifth coring run was started. While washing to bottom, a 90% loss of returns occurred, but gradually dropped to less than 30%. It was decided to continue the coring run, and then run a temperature survey later to locate the LCZ. Between 4253 m and 4255 m (13 955 ft and 13 963 ft) a 2.2-m (7-1/2-ft) length of core was obtained (Fig. 13). A Laboratory temperature survey was then conducted, which revealed the LCZ to be

Fig. 12. Core Run No. 4: 1.35 m (4.4 ft).

Fig. 13. Core Run No. 5: 2.2 m (7.5 ft) long taken from between 4253 to 4255 m (13 955 to 13 963 ft).

around 724 m (2375 ft). While tripping in the next day to cement, an obstruction was encountered at 537 m (1762 ft) in the 34-cm (13-3/8-in.) intermediate casing. A DOT impression block confirmed that the casing had collapsed below 537 m (1762 ft). On December 23, the Laboratory downhole TV camera was lowered into the hole to reveal that water was leaking into the casing from a split section just below a collar at 537 m (1762 ft). It was decided to roll out the collapsed portion of the casing in steps from 18-cm (7-in.)-diam rollers to 24.4-cm (9-5/8-in.)-diam rollers. Attempts to roll out the casing however, had to be abandoned because no progress was made. On December 25, the second downhole TV camera run was conducted but the water above the obstruction was too murky for a clear picture. A 10-cm (4-in.) swedge tool (Fig. 14) was then run in and the next day a larger, 20.3-cm (8-in.), swedge tool was tripped in and out of the hole, followed by a 24.4-cm (9-5/8-in.) roller. When on deck, this roller was found to have gray sand and clay material on its worn rollers. A 50.1-cm (10-3/4-in.) roller was then run in, and after 14 h of rolling, it opened the casing and was lowered freely to 553 m (1814 ft). Another obstruction was found there, and high resistance developed when attempts to roll were made. When the roller was pulled, three rollers and a retainer were missing. An unsuccessful magnet run was made, and rolling the casing with the 31.1-cm (12-1/4-in.) casing roller tool resumed

Fig. 14. Swedging tool used in 34-cm (13-3/8-in.) casing.

the following day, on December 28. At 542 m (1777 ft) the tool torqued up and was pulled out of the hole. The condition of the casing at this time is shown in Fig. 15.

The third TV run was then made, which revealed a hole in the casing at the depth of the F0 stage collar in the 34-cm (13-3/8-in.) casing. A portion of this stage collar appeared to be missing and the casing looked egg-shaped below this depth. On December 29, while using an 20.3-cm (8-in.) swedge tool with a 31.1-cm (12-1/4-in.) roller directly above it, a solid obstruction was hit at 548 m (1800 ft). An impression block was run in, and upon retrieval showed a crescent-shaped impression on its face. At first, this was thought to be one of the missing rollers, but after the fourth TV run, the crescent shape turned out to be a large tear in the casing, 1.2 cm to 1.9 cm (1/2 in. to 3/4 in.), folded inward like a tin can lid at 546 m (1792 ft). Splits measuring 0.63 cm (1/4 in.) to 7.6 cm (3 in.) wide were also seen between 537 m (1762 ft) and 543 m (1783 ft). Rubble could be seen through these splits.

Shortly after the TV run, milling to 547 m (1796 ft) with a 21.5-cm (8-1/2-in.) concave-faced mill began. A tapered, 31.1-cm (12-1/4-in.) mill was then tripped in hole and worked between 544 m (1786 ft) and 546 m (1792 ft). This tool, however, was unable to pass 546 m (1792 ft). A fifth TV run was then attempted, but was aborted because of water in the borehole. Milling resumed and the hole was cleared for a magnet run made on December 31; no junk was removed.

On January 1, 1980, another impression block was run, which showed the previous day's milling had tapered the casing inward at 547 m (1795 ft). Following this, milling runs, swedge runs, impression block runs, and magnet runs continued for 4 days. On January 6, the seventh TV run revealed the casing to have deteriorated since previous TV runs. Jagged pieces of metal were encountered just below 540 m (1771 ft). The camera could not be passed through this point and was pulled out of the hole.

At this point, it was thought that a spot cement plug could be placed to stabilize the bad casing. Twelve burlap sacks were wadded up and pushed down to 551 m (1809 ft). This was topped with 0.6 Mg (1400 lbs) of 20/40 sand. The sand was tagged at 548 m (1800 ft). Above this, 100 sacks Class H cement were pumped in. Later on that day, no cement tag could be found above 543 m (1782 ft). A second plug attempt began when six burlap bags, each wrapped in wire, were pushed downhole to 551 m (1808 ft). Halliburton then pumped in 100 sacks Class B cement with 2% CaCl_2 and a thixotropic additive. This cement was tagged at 549 m (1801 ft). A third cementing attempt was made using the previous mix, and this cement was tagged at 550 m (1800 ft). The fourth plugging attempt took place on January 8, beginning with 50 bbls of high-viscosity mud with 30% LCM being pumped downhole. One hundred sacks of Halliburton thixotropic cement with 3% CaCl_2 followed. Ten barrels of water were then pumped in and three stands were pulled out of the hole and set aside. Another 100 sacks of thixotropic cement were then injected into the borehole. This fourth plug was tagged at 548 m (1799 ft). On the same day, the fifth plug, consisting of two individual batches of 100 sacks each were tagged at 547 m (1797 ft). The sixth plugging attempt occurred on January 9 when 200 sacks of Halliburton Halco-Light cement, containing 3% CaCl_2 , 12-1/2% Gilsonite and 1/4% Flocele, were pumped downhole. The last tag was at 483 m (1585 ft).

Milling began again, but on January 11, while grinding through cement at 540 m (1774 ft), all returns were lost. A seventh cementing was conducted by Halliburton; open-ended drill pipe was lowered to 547 m (1796 ft) and 200 sacks Class B thixotropic cement at 13.7 ppg with 12-1/2% Gilsonite and 1/2% Flocele were pumped downhole. This cement was tagged at 536 m (1759 ft). Milling resumed, but circulation was lost again at a depth of 538 m (1767 ft) and the eighth cementing effort began. This plug consisted of 200 sacks thixotropic with 3% CaCl_2 , 12-1/2% Gilsonite and 1/2% Flocele. The plug top was found at 520 m (1707 ft). Milling began and continued to 548 m (1800 ft) with no circulation loss. Milling on the obstruction at 548 m (1800 ft) continued using a succession of concave-faced, 31.7-cm (12-1/2-in.)-diam mills, tapered mills, and flat-faced mills, all with full returns.

Gradual working down through the collapsed casing section continued with a variety of mills, magnet runs, TV runs, swedges, string reamers, an unsuccessful attempt to place an aluminum alignment sleeve, and an aborted plan to evacuate the hole with nitrogen to provide a clearer TV picture. Finally, on February 1, a 31.1-cm (12-1/4-in.) mill and swedge assembly was run through the casing down to 2789 m (9150 ft). The lower sections of the hole were cleaned below 3353 m (11 000 ft), but on February 7, the circulation was again lost at 716 m (2350 ft). Cementing and milling in the 34-cm (13-3/8-in.) casing continued until March 22, when it was decided to discontinue the effort to seal off the LCZ at 716 m (2350 ft), clean the hole to the casing set point and run the 24.4-cm (9-5/8-in.) casing as soon as possible. For detailed casing collapse history, see Appendix D.

The precementing cool-down of the hole began March 25 and continued through to March 27. On March 28, running of the 24.4-cm (9-5/8-in.) production casing was completed to the design depth of 3529 m (11 578 ft). Shortly afterwards, the cool-down flow through the casing was started. On March 31, the bottom 3048 m (1000 ft) of the production casing was cemented with 75 bbls of cement consisting of 237 sacks Class H (16.6 lbs per sack slurry) with 80% silica flour. Following the cementing operation, circulation was maintained in the casing through open-ended drill pipe to produce a slow cure of the cement. On April 3, a Dia-Log caliper log was run to 3504 m (11 495 ft) to obtain baseline readings for comparison with future measurements. To protect the production casing, rubber protectors were installed on the

Fig. 15. Condition of hole casing before cementing attempts. Diagram illustrates the 34-cm (13-3/8 in.) casing tear at approximately 546 m (1792 ft.)

drill pipe joints during subsequent downhole work. The casing string float shoe was drilled out and drilling on the junk at 3534 m (11 594 ft) began.

Milling continued until April 24, when the first new footage in 126 days, since December 21, 1979, was made from 4248 m (13 937 ft) to 4249 m (13 940 ft). Drilling continued, interrupted only by magnet runs and single shot surveys, increasing the new hole to 4420 m (14 501 ft). On May 1, while tripping out of the hole with Bit No. 137, a drill collar box parted, leaving two drill collars, plus all of the BHA, in the hole. By the next morning, DOTCO had picked the fish up off the bottom and it was on deck. On May 2, the sixth coring run was conducted, resulting in approximately 100 cm (39 in.) of core from between 4420 m (14 501 ft) and 4421 m (14 504 ft) (Fig. 16). Drilling then increased the borehole to 4532 m (14 869 ft), 162 m (531 ft) short of the design depth, 4694 m (15 400 ft). With the possibility of only one more bit run needed to complete EE-2, it was decided to make another coring run.

On May 6, the seventh coring run produced 0.6 m (2 ft) of core from below 4560 m (14 962 ft) (Fig. 17). Rotary drilling with Bit No 142, STC 7GA was resumed, increasing the hole depth at approximately 5 m/h (15 ft/h) to 4655 m (15 273 ft). On May 8, Bit 142 lost a cone downhole, which was retrieved with a magnet run. On May 11, two tests runs of the Maurer turbodrill were made

Fig. 16. Core Run No. 6: 100 cm (39 in.) taken from between 4420 to 4421 m (14 501 to 14 504 ft).

Fig. 17. Core Run No. 7: 60 cm (2 ft) taken from below 4560 m (14 962 ft).

using a 5-7/8-in.-diam bit to the final footage of EE-2 from 4655 m (15 273 ft) to a total depth of 4660 m (15 289 ft). A Laboratory TV run was made on May 13 to inspect the casing wear suspected to be at 204 m (670 ft). Nothing unusual could be seen in four passes of the camera at that depth. A Laboratory three-arm caliper survey conducted on May 14 confirmed, however, a "thinout" zone of 0.5 cm (3/16 in.) in the 24.4-cm (9-5/8-in.) casing at 205 m (673 ft). On May 16, the Brinkerhoff-Signal rig was released from EE-2. For a lithology of EE-2 below 2924 m (9600 ft), see Plate 2. Photographs taken throughout the drilling history of EE-2 are shown in Appendix E.

V. DRILLING MEDIA

The drilling fluid consisted mainly of fresh water with moderate amounts of various additives furnished by NL Baroid/NL Industries, Inc.¹⁹ Specific formulations for the different cased- or open-hole intervals in the hole are listed in Table I.

To provide adequate hole-cleaning action while drilling the 66-cm (26-in.) and the 44.5-cm (17-1/2-in.)-diam hole sections, an inverted rheology (YP>PV) was maintained by using a polymeric flocculant and reducing the amount of deflocculants. Although filtration-reducing agents were used in the previous two holes (GT-2 and EE-1) while drilling through the mud-making Abo Formation Shale, none was used in EE-2. No appreciable problems in mud-making or side-wall instability were encountered as a result of this omission. Lost circulation occurred at 317 m (1037 ft), which resulted in the loss of 175 bbls of fluid, but circulation was regained with the addition of 2% cottonseed hulls. A known loss zone at 576 m (1890 ft) required pretreatment of the

TABLE I
MUD FORMULATIONS USED DURING THE DRILLING OF EE-2

Depth Interval	Hole Diameter	Formation	Mud Formulation
25 m to 544 m (82 to 1780 ft)	66 cm (26 in.)	Volcanic Tuff; Shale and Clay	Water, Bentonite, Caustic Soda, Carbonox, Cottonseed Hulls, Aspen Fiber
544 to 731 m (1780 to 2390 ft)	44.5 cm (17-1/2 in.)	Shale and Clay; Limestone	Water, Bentonite, Cottonseed Hulls, Sawdust, Aspen Fiber
731 to 3552 m (2390 to 11 616 ft)	31.1 cm (12-1/4 in.)	Granitic Basement Complex	Water, Caustic Soda, Corrosion Inhibitors, Torq-Trim II, MF-1
3552 to 4676 m (11 616 to 15 289 ft)	22.2 cm (8-3/4 in.) Open Hole	Granitic Basement Complex	Water, Caustic Soda, Corrosion Inhibitors, Torq-Trim II, MF-1 or Selec-Floc

drilling fluid with 20% LCM. As a result, only 35 bbls of fluid were lost to the formation at this depth.

When the cavernous limestone zone at 731 m (2390 ft) was reached, drilling without returns was begun, until the 34-cm (13-3/8-in.) casing was set and cemented. However, the cement seal was broken numerous times during subsequent drilling, which required additional recementing. Approximately 3500 bbls of mud and LCM were lost into this zone during later sealing attempts. Water transport trucks were utilized during these high loss operations to augment the on-site water storage and supply.

Drilling in the Precambrian crystalline basement complex rock below 734 m (2400 ft) required a completely different drilling fluids program. Problems associated with this portion of the hole included extreme abrasiveness, extreme temperatures as high as 340°C (644°F), zones of small water loss, and apparent instability in some of the fractured/altered zones. Directional drilling below the 1835-m (6000-ft) depth resulted in a hole deviation of 35° from the vertical, which (in combination with the abrasive formation) caused significant torque and drag problems. Additions of the lubricity producing

agent Torq-Trim II, a triglyceride-alcohol mixture, were made batchwise in 100-bbl pill of 2-ppg concentration. The effects of the lubricant were temporary however, at temperatures greater than 190°C (394°F), so that replenishment was necessary. Without lubricant, the drilling torque was 600 to 750 A, but with the addition of Torq-Trim II the torque was reduced to less than 400 A. Several twist-offs of the drill string were attributed to excessive torque, in combination with corrosion pitting (see Section XIII). Therefore, when the torque became excessive, Torq-Trim II was added as needed to continue drilling. The large volume (10 000 bbls) of circulating fluid required for adequate cooling made the maintenance of lubricity extremely expensive. Approximately one-third of the cost of the total mud program was attributed to the necessary use of Torq-Trim II. (For Baroid's graphic record of mud costs versus depth see Appendix F.)

Furthermore, the high torque and drag placed a high priority on minimizing drill pipe failure due to corrosion. Inhibition of corrosion was also made more expensive by the high-temperature and large circulating volumes. Control was maintained by the use of an ammonium bisulfite oxygen scavenger (COAT 777), an organic descaler (SURFLO H-35), and a basic pH. Corrosion rates were largely held well below the standard 2 lbs/sq ft/yr. Approximately one-third of the cost of the total mud program was caused by the necessary moderation of corrosion problems.

Prior to cementing the 24.4-cm (9-5/8-in.) casing, a 326-bbl pill of 16-ppg barite mud was circulated ahead of the cement slurry. All of this mud remained in the annulus to support the casing above the cement column.

VI. DRILL BIT HISTORY

Initial drilling was done with 66-cm (26-in.)-diam, tricone milled-tooth roller bits through the conductor pipe to a depth of 544 m (1785 ft). A 50.8-cm (20-in.) surface casing was then placed and cemented. Drilling continued through and below the surface casing using 44.5 cm (17-1/2 in.) tricone drill bits, both milled tooth and TCI button types, to a depth of 790 m (2593 ft). At this depth a 34-cm (13-3/8-in.) intermediate casing was set and cemented in place. Below the intermediate casing, the hole was drilled to 3528 m (11 576 ft) using 31.1-cm (12-1/4-in.) TCI button bits, with roller reamers for hole gauge control. At this depth, the hole size was transitioned to 22.2-cm (8-3/4-in.) by first drilling 3 m (10 ft) of hole with a 27.9-cm

(11-in.) TCI bit and another 3 m (10 ft) with a 24.4-cm (9-5/8-in.) bit. The remainder of the hole, to a final depth of 4661 in. (15 289 ft), was then drilled with 22.2-cm (8-3/4-in.) TCI button bits, with roller reamers on the drilling assembly to maintain hole size (Figs. 18-20).

The moderate temperature, 200°C (400°F), portion of the EE-2 wellbore was drilled with available sealed friction and roller bearing bits with tungsten carbide cutting structures. Bit life was severely reduced in all cases due primarily to gauge wear. Considerable attention was given to obtaining minimum cost per foot performance by proper selection of bit type and drilling parameters.

While drilling with the 22.2-cm (8-3/4-in.) bits, problems occurred when the 34-cm (13-3/8-in.) intermediate casing string collapsed at ~518 m (~1700 ft). The 22.2-cm (8-3/4-in.)-diam hole at that time was at ~4249 m (13 937

Fig. 18. Gaging a carbide button bit.

Fig. 19. Wear on a 31.1-cm (12-1/4-in.) STC F-9 bit. It drilled 5.3 m (17 ft) in 1.5 h in biotite granite gneiss.

Fig. 20. Extreme wear due to junk in the hole, on Bit No. 86, on HTC 31.1-cm (12-1/4-in.) J-55. This bit drilled 19.5 m (63 ft) in 6.5 h in biotite granitic gneiss and was pulled out from 11 289 ft.

ft) depth. The final 24.4-cm (9-5/8-in.) production casing was run in to just above the transition zone immediately after opening the collapsed interval. This was followed by drilling to the final depth of 4661 m (15 289 ft), using downhole motors and building-type rotary drilling assemblies for directional and inclinational control.

Thirty-one 22.2-cm (8-3/4-in.)-diam bits were used to drill the open hole portion of EE-2. This uncased section was directionally drilled and will be the location for fractures that are to connect EE-2 with the production hole, EE-3, and form the reservoir. The STC 7GA bit (Fig. 21) proved to be the preferred bit for drilling this open-hole interval; 20 STC 7GA bits were used.

Hole gauge was maintained by the unique wear pads, introduced by the STC, on each of the bit's three shanks.

A tabulation of bit sizes, types, and quantities used is shown in Table II.

VII. CORING

Previous coring in GT-2^{10,13} and EE-1,¹⁵ using modified JOIDES bits, resulted in fair core recovery and bit life at moderate depths. Diamond core bits were also used, which produced good core, but their extremely short bit life (~10 ft) proved too costly to be considered for further use.

A prototype core bit was developed by STC combining General Electric Company "Stratapax" elements with roller TCI cutters for use in

TABLE II
BIT TYPES USED IN EE-2^b

Bit Diam cm (in.)	Type ^a	Quantity	Maximum Depth Along Drill String m (ft)
66 (26)	Milled Tooth	4	544 (1785)
44.5 (17-1/2)	Button Insert	5	790 (2593)
31.1 (12-1/4)	Milled Tooth Button Insert	18 78	(Drilled Cement Plugs) 3528 (11 576)
11	Button Insert	1	Transition Interval between 31.3 cm (12-1/4 in.) and 22.2 cm (8-3/4-in.) Holes
24.5 (9-5/8)	Button Insert	1	
22.2 (8-3/4)	Button Insert	31	
			4660 (15 289)

^aSee Appendix C for complete list of drill bit details, drilled intervals, and bit hydraulics.

^bThe day-to-day activities covering the use of the above bits appear in Appendix G.

redrilling GT-2.¹⁶ The core was shaped by six Stratapax elements as it entered the 7.6-cm (3-in.) i.d. core barrel, using the roller cutters for the major drilling of the hole.

During the drilling of EE-2, cores were planned to be obtained at approximately 183 m (600 ft) intervals, below 3353 m (11 000 ft). To accomplish this, six hybrid roller cone Stratapax bits with Polycrystalline Diamond Cutters (PDC) were purchased from the STC (Fig. 22). The bits are 20-cm (7-7/8-in.) o.d. by 7.6-cm (3-in.) i.d. and consist of four cones with TCI buttons and four (instead of the prototype six) PDC pads mounted on tungsten carbide studs.²⁰ Two Hycalog 15.88-cm (6-1/4-in.) o.d. by 4.6-m (15-ft)-long core barrels were also purchased.

Table III is a summary of the coring runs made in EE-2. Rotational speed varied from 35 to 50 rpm with 4.5 to 9 Mg (10 000 to 20 000 lbs) weight. Every bit was pulled when the penetration rate slowed to about half. Bits 1 and 3 could have been rerun had the PDC (Stratapax) pads and studs been replaced. The bit from Run 2 was in good condition and was reused in Run 7. The bit from Run

TABLE III

SUMMARY OF CORING OPERATIONS IN EE-2
(All bits were Smith Tool Hybrid Roller Cone/PDC)

Run No.	Date	Depth m (ft)	Cored Interval m (ft)	Recovery (%)	Penetration Rate min/m (min/ft)	Cone Teeth	Bit Condition			Remarks Recommendations	Rock Type
							Cone Bearings	Gauge Wear	PDC Pads		
1	11/11/79	7577-7579 (11 737-11 743)	1.8 (6)	79	39 (12)	2	4	None	8	Rebuild and replace PDC studs; use again.	Biotite grano- diorite gneiss; fracture oriented at 3° from vertical.
2	11/20/79	3739-3741 (12 266-12 275)	2.7 (9)	0	19 (6)	4	5	1/16-in.	2	Bit could be rerun as is.	No recovery; drilled through fractured/alterd zone.
3	11/26/79	3916-3918 (12 848-12 856)	2.4 (8)	91	59 (18)	1	3	None	3	Rebuild and replace PDC studs; use again.	Metavolcanic (dacite) intruded by granodioritic material.
4	12/8/79	4101-4104 (13 454-13 464)	3.0 (10)	41	59 (18)	3	8	1/16-in.	8	Scrap pile.	Biotite grano- diorite.
5	12/21/79	4253-4256 (13 955-13 962)	2.3 (7.5)	100	49 (15)	1	4	None	3	Bit could be rerun as is.	Biotite-amphibole- feldspar gneiss intruded by biotite grano- diorite.
6	5/2/80	4420-4421 (14 501-14 504)	1.0 (3.3)	100	19 (6)	4	6	1/16-in.	8	Scrap pile.	Biotite-amphibole- feldspar gneiss, similar to Core Run No. 5.
7 Rerun No. 2 Bit	5/6/80	4560-4562 (14 962-14 966)	1.2 (4)	40	26 (8)	4	6	1/8-in.	8	Scrap pile.	Biotite grano- diorite gneiss, similar to Core Run No. 1.

Note: Cone teeth and bearings, and PDC pads are rated on a scale of 1 (like new) to 8 (completely ruined).

5 was also in good condition (Fig. 22), but the studs were broken off in Run 6 (Fig. 23).

Orientation of the core was attempted in core runs 2 and 6. The first orientation used an Eastman Whipstock core orienting tool protected with a heat shield. The bit was pulled after cutting 2.7 m (9 ft), to preserve the film within the orienting tool. However, the film was found blackened and the tool had suffered severe heat damage. There was also no core recovery and the cuttings indicated that the run had been attempted in a highly fractured, altered zone. The second orientation attempt was made with an Eastman Whipstock Magnetic Multishot, with a wireline insertion and recovery mechanism. During insertion, the overshot grapple on the wireline came unscrewed making early recovery impossible. The tool was withdrawn with the bit and it was found that excessive heat had damaged both the film and the tool.

Fig. 21. Used STC 7GA bit.

Fig. 22. The hybrid roller cone Stratapax coring bit.

Fig. 23. Bit No. 6 after a successful coring run, showing the broken studs of the Stratapax units.

VIII. DIRECTIONAL DRILLING

The drilling plan for EE-2²¹⁻²⁴ required that the lower portion of the borehole be inclined at 35° from the vertical, and that the borehole direction be contained in the NE quadrant so that, in plan view, the trajectory would be perpendicular to the assumed fracture direction (Fig. 24), thus creating the greatest amount of access to the reservoir rock. As drilling progressed into the 35° slant portion of the hole, it was necessary to further reduce the magnitude of axial and torsional drag between the drill string and the borehole. Essentially all of the drill collar string was replaced with smaller outside diameter HWDP (Drilco Division of Smith International, Inc.) to reduce contact area.

A. Motor-Driven Equipment

Figure 25 illustrates the directional drilling equipment and instrumentation used with a description of the major elements and functions.

The two key elements of this directional drilling system were the downhole motor and steering tool. The directional drilling operations used three different types of motors and three separate steering tools, as presented in Table IV. The high-temperature turbodrill (Fig. 26) was developed as a joint effort between Los Alamos and MEI of Houston, Texas. It was necessary to run the steering tool in all instances in which the turbodrill was used except for the last two runs at the bottom of the hole. A Dewar-type heat protection shield was required at higher temperatures.

TABLE IV
DOWNHOLE DIRECTIONAL MOTORS AND STEERING TOOLS USED IN EE-2

Downhole Motors					
Type	Diam	Temperature Rating	Length	Supplier	Key
Positive Displacement	17.1 cm 6-3/4-in.	~175°C (350°F)	60.0 m 19.9 ft	Baker Service Tools Houston, Texas	BPDM
Positive Displacement	19.7 cm 7-3/4-in.	~155°C (310°F)	60.0 m 19.9 ft	Dyna-Drill, Smith Int'l, Irvine, California	DDPDM
Turbine	19.7 cm 7-3/4-in.	~320°C (610°F)	6.3 m 20.7 ft	Maurer Engineering, Inc., Houston, Texas	MEI
Steering Tools					
Sensor Type	Temperature Rating		Service Company	Key	
Magnetometer With Inclinator	275°C ^a (527°F)		Eastman-Whipstock, Houston, Texas	DOT	
Magnetometer With Inclinator	316°C ^b (600°F)		Sperry-Sun, Houston, Texas	SST	
Magnetometer With Inclinator	200°C ^c (400°F)		Scientific Drilling Controls, Irvine, California	EYE	

^aLimited by elastomers used in motor drive system.

^bRequires heat shield.

^cRun without heat shield up to 200°C (400°F).

A turbine tachometer (rpm indicator) was developed to provide a surface indication of downhole motor speed. Its operation was based upon a pressure pulse produced during each revolution of the turbine shaft by a perturbation in the blading of the motor. The pulse was transmitted through the fluid column in the drill string to the surface where it was detected and processed. Nitrogen-operated, pressure-pulse dampers were assembled and placed in series in

Fig. 24. Lower borehole design of the Phase II system. [total depth (TD), total vertical depth (TVD)].

the mudline at the outlet of the triplex rig pumps. These dampers were required to improve the signal resolution of the turbodrill tachometer.

A method of damping vibration and shock transmitted from the bit to the motor was necessary, and two high-temperature rated shock absorber tools were purchased.

A bent-sub assembly ($1/2$ to $2-1/2^\circ$), containing a muleshoe orienting sleeve, was included in the assembly just above the motor to provide a directed side thrust to the bit.

A nonmagnetic drill collar (monel) was included directly above the bent-sub to eliminate magnetic disturbance to the steering tool magnetometer by the mass of steel contained in the assembly above and below the tool.

Thirty-three motor-driven runs were made in EE-2 (Table V). Of the three types of downhole motors used, the Maurer turbodrill (Fig. 26) demonstrated the greatest capability to operate in hostile downhole environments (Table VI). All

TABLE V

SUMMARY OF AZIMUTHAL DIRECTIONAL DRILLING RUNS FOR WELL EE-2
(Note: All runs with 12-1/4-in.-diam bits.)

Directional Drill Motor Run No.	Drill Motor ^c	Steering Tool Service ^d	Bent Sub Angle	Measured Depth, Ft ^a	Borehole Deviation ^e	Distance Drilled, Ft	Shock Absorber ^b	Remarks
1	MEI	N/A	0	4912	5-3/4°, S64 W	57	Yes	First field trial of 7-3/4-in.-diam MEI turbodrill.
2	DDPDM	DOT	2°?	6492	4-1/2°, S64 W	0	No	
3	DDPDM	C	2°?	6518	4-1/4°	26	No	Steering tool damaged.
4	DDPDM	-----	2°?	6597	3°	79	No	
5	DDPDM	-----	2°?	6619	4°	22	No	
6	DDPDM	-----	2°?	6818	4-3/4°, N37 W	100	No	
7	BPDM ^a	-----	2°	6914	5-1/2°, N6 W	45	No	KOP.
8	BPDM	-----	1-1/2°	7003	5-3/4°, N16 E	89	NO	
9	DDPDM	-----	2°?	7743	15°, N13 E	54	No	
10	MEI	DOT	1-1/2°	8326	16°, N13 E	58	Yes	All subsequent runs required intermediate reaming of hole.
11	MEI	DOT	1-1/2°	8328	-----	2	Yes	
12	MEI	DOT	1-1/2°	8414	16°, N17 E	86	Yes	Considerable operational difficulties experienced from 8300 to 9303 ft with steering tool.
13	MEI	DOT	1-1/2°	8545	13-3/4°, N37 E	131	Yes	
14	MEI	DOT	1-1/2°	8575	-----	30	Yes	
15	MEI	DOT	1-1/2°	8757	-----	0	Yes	
16	MEI	DOT	2°	9035	-----	60	Yes	Turbine would not rotate.
17	MEI	DOT	2°	9035	-----	0	Yes	
18	MEI	DOT	1-1/2°	9082	15°, N34 E	42	Yes	
19	MEI	DOT	2°	9188	-----	106	Yes	
20	MEI	DOT	1-1/2°	9311	13-1/2°, N40 E	123	Yes	
21	MEI	DOT	1-1/2°	9363	13-1/4°, N42 E	52	Yes	

TABLE V (CONT)

Directional Drill Motor Run No.	Drill Motor ^c	Steering Tool Service ^d	Bent Sub Angle	Measured Depth, Ft ^a	Borehole Deviation ^e	Distance Drilled, Ft	Shock Absorber ^b	Remarks
22	MEI	SST	2°	9363	-----	0	Yes	Turbine would not rotate, steering tool failed.
23	MEI	EYE	2°	9467	12-1/4°, N44 E	104	Yes	
24	MEI	EYE	2°	9513	12-1/4°, N44 E	46	Yes	
25	MEI	EYE	2°	9531	-----	18	Yes	Reached temperature limit of shock absorbers.
26	MEI	EYE	2°	9776	13°, N59 E	10	No	
27	BPDM	EYE	2°	9838	15-1/2°, N74 E	51.5	No	
28	BPDM	EYE	2°	9850	-----	10	No	Reached temperature limit of BPDM.
29	MEI	EYE	2°	9912	13°, N59 E	62	No	
30	MEI	EYE	2°	10 035	-----	118	No	
31	MEI	EYE	1-1/2°	10 552	21°, N70 E	127	No	Motor run used to increase inclination.
32	MEI	-----	-----	15 282	35°	8	No	Motor run to extend depth.
33	MEI	-----	-----	15 289	35°	7	No	Motor run to extend depth.

^aDepth at end of run.^bNew 5-3/8-in. MEI turbodrills run to test for EE-3 use.^cSee Key Table IV.^dBased on single-shot magnetic surveys.^eDistance measured along the wellbore.

TABLE VI
MOTOR ASSEMBLY PERFORMANCE SUMMARY

<u>Motor Type</u>	<u>Number of Runs</u>	<u>Average Hours Per Run</u>	<u>Average Footage Per Run</u>	<u>Average ROP^b Per Run (ft/h)</u>
MEI	21 ^a	2.8	59.8	21.6
DDPDM	6	4.5	54.7	12.3
BPDM	4	7.8	48.8	6.2

^aDoes not include two short test runs of 5-3/8-in.-diam MEI turbodrills at bottom of hole.

^bRate of penetration.

of the positive displacement motors suffered thermal degradation of the stator at temperatures approaching 200°C (400°F). The details of Run 31 from Table V are shown in Table VII.

The general directional drilling procedure followed was:

- Rotate the drilling motor while hanging above the rotary table, using rotary water swivel.
- Run the drilling motor assembly close to bottom.
- Using the rotary water swivel, check for motor rotation at bottom.
- Make up a 20 m (60 ft), two joints, length of drill pipe.
- Add the double joint stand; assemble gooseneck head with a wireline pack-off.
- Run steering tool to bottom; latch into orienting sub.
- Back-rotate the drill string to compensate for the reactive bit torque with respect to the desired downhole tool face orientation.
- Start motor and drill off; monitor BHA orientation with surface readout steering tool.
- If the desired azimuth is not obtainable at start, correct azimuth in small increments while drilling.
- Drill ahead; correct azimuth of tool face as necessary.

TABLE VII

TYPICAL MEI HIGH-TEMPERATURE 7-3/8-IN.-DIAM BODY TUBRODRILL PERFORMANCE IN EE-2
RUN 31, TABLE V

Date:	October 12-13, 1979
Depth:	3180 to 3217 m (10 433 to 10 522 ft)
Drilling Interval:	~60 m (119 ft)
Approximate Formation Temperature:	310°C (500°F)
Shock Absorber:	None
Bit:	STC Q9JL, 31.1-cm (12-1/4-in) in diameter
Bit Load:	≤89 KN (20 000 lb _f)
Bent Sub:	1-1/2°
Flow Rate:	77 Pump Strokes/min, ~22.52 l/s (357 gpm)
Estimated Rotary Speed:	300 to 400 rpm
Inclination Angle Change Achieved:	~1-1/2°
Total Rotating Time:	>4.5 h
Nominal Penetration Rate:	>7.9 m/h (26 ft/h)
Condition of Bearing:	No broken races, but estimated <u>≤</u> 1/2 h drilling life remaining.

- Drill down a second two-joint stand if drilling conditions and angle change warrant.

The three-cone roller bearing insert bits proved the most useful for directional drilling in granite. The majority of runs were made either with an IADC code 835 bit or the improved geothermal bit.

The turbodrill played a key role in controlling the inclination of the borehole. In drilling below approximately 2743 m (9000 ft), a curvature of 2°/100 ft was required to attain a 35° inclination by approximately 3352 m (11 000 ft). On October 11, a single shot survey indicated the borehole

Fig. 25. Drilling equipment and instrumentation used to directionally drill EE-2.

inclination to be only $17\text{--}1/4^\circ$ from vertical at 3275 m (10 418 ft). In order to increase the angle, the turbodrill was used to increase the inclination to 21° by 3216 m (10 552 ft) as shown in Table V.

Two turbodrill runs were made at the bottom of the hole in an attempt to deepen the hole without subjecting the casing to rotational drill string wear. However, frictional drag in the deviated hole was so great that it was impossible to tell if the bit was being properly loaded, and drilling was terminated after making very little hole. This test run of the 5-3/8-in.-diam Maurer turbodrill did prove operational capability of this unit in a hot hole although the "Eye" tool used with it failed.

B. Rotary-Driven Build Assembly

Once the desired course direction was attained, rotary-driven angle (or inclination) building assemblies were used to increase the hole angle to 35° from vertical.

After experimentation with

increasingly strong build-up assemblies, satisfactory performance was finally derived from the multistabilizer/reamer assembly described in Table VIII. Roller reamers were used as wall contact tools instead of the more common blade or pad type stabilizers due to the extreme torsional drag and rapid abrasive wear that occurred when drilling with the latter (Fig. 27).

Operation of the build-up assemblies was primarily one of determining the proper weight on the bit and a rotary speed that provided the desired rate of inclination build, penetration rate, and walk rate. Calculations were performed, and later verified operationally, to determine the maximum bit

TABLE VIII

TYPICAL BOTTOM-HOLE ASSEMBLIES FOR DIRECTIONAL DRILLING IN WELL EE-2

BHA for Drill Motor Azimuthal Angle Alteration	BHA for Rotary Inclination Angle Increase ^b	BHA for Rotary Inclination Maintenance ^c
31.1-cm (12-1/4-in.) -diam bit	31.1-cm (12-1/4-in.) -diam bit	22.2-cm (8-3/4-in.) -diam bit
Shock Absorber	3-Point BH Reamer	6-Point BH Reamer
Drill Motor	Crossover Sub	17.1-cm (6-3/4-in.) -diam short drill collar
Crossover Sub	17.1-cm (6-3/4-in.) -diam Monel drill collar	3-Point String Reamer
Bent-Orienting Sub	17.1-cm (6-3/4-in.) -diam short drill collar	17.1-cm (6-3/4-in.) -diam Monel drill collar
20.3-cm (8-in.) -diam Monel collar	17.1-cm (6-3/4-in.) -diam drill collar	3-Point string Reamer
Twelve 20.3-cm (8-in.) -diam drill collars	Crossover Sub	Four 17.1-cm (6-3/4-in.) -diam drill collars
21 Joints HWDP ^a	3-Point String Reamer	20 Joints HWDP ^a
	20.3-cm (8-in.) -diam drill collar	Drilling Jars
	Ten 20.3-cm (8-in.) -diam drill	13 Joints HWDP ^a
	8 Joints HWDP ^a	
	Drilling Jars	
	13 Joints HWDP ^a	

^a12.7-cm o.d., 74.3 kg/m (5-in. o.d., 50 lb/ft).^bBuild assembly.^cPacked-hole (hold assembly).

Fig. 26. Downhole turbodrill developed by the Los Alamos National Laboratory and MEI of Houston, Texas

Fig. 27. Typical downhole assemblies: (a) packed hole, and (b) deviating.

weight to be applied without creating a point of tangency between the first and second reamer. Considerable experimentation was also performed to define a relationship between rotary speed and the direction and rate of hole walk. Essentially no predictable relationship was determined, therefore the rotary speed for minimum cost per foot drilling was used.

C. Rotary-Driven Hold Assembly

Rotary-driven hold or lock-in assemblies were used to maintain a desired borehole inclination and azimuth orientation (Fig. 27). Their primary application occurred in the vertical section of hole from the bottom of the 34-cm (13-3/8-in.) casing at 770 m (2463 ft) to the kick-off point at approximately 2.2 km (7000 ft) and through the 35° slant portion of the hole from 3.6 km (11 600 ft) measured depth to TD of 4.7 km (15 292 ft). A typical hold assembly

is detailed in Table VIII. Operation of the hold assembly was directed primarily at minimum cost per foot parameters.

D. Directional Surveys

During rotary drilling operations, single-shot directional surveys were conducted at regular intervals. At shallow depths and moderate temperatures, a conventional single-shot tool was run either on a 0.23-cm (0.092-in.) slickline or dropped in go-devil fashion prior to tripping the drill string. As temperatures increased to above 121°C (250°F), however, it was necessary to utilize a smaller diameter single-shot tool inherently more heat resistant and encase it in a Dewar-type heat shield. Additionally, as borehole inclination increased to 35°, it was necessary to substitute a 1.6-cm (5/8-in.) braided wireline to effectively handle the increased drag on the wireline while retrieving the survey tool. At temperatures above 200°C (400°F), it was necessary to institute various operational techniques designed to cope with the elevated temperatures. For example, precautions were taken to exclude water vapor from both inside and outside the Dewar flask.

IX. CASING

A. Conductor Pipe

Before the arrival of the drilling rig, the 71-cm (28-in.)-diam conductor pipe was set to approximately 25 m (83 ft) below ground level. This 0.64-cm (0.25-in.) wall thickness pipe was concreted in place up to the floor of the 0.6 m (2 ft) deep cellar, made of 2.1-m (7-ft)-diam corrugated metal pipe (CMP).

B. Surface Casing

During the initial run-in of the 50.8-cm (20-in.) casing on April 18, 1979, indications of excessive torque on the power tongs during make-up halted further placement. An inspection revealed that nine casing collars had undersized eight round threads, which prevented proper make-up. Running of the casing was delayed until April 20, while new casing collars were being procured.

The surface casing string was set at 544 m (1780 ft) and consisted of 50.8-cm (20-in.) API casing set in the 66-cm (26-in.) hole as follows:

- float shoe, stab-in type
- 1 joint, 8 round, 133 lb, K-55
- float collar

30 joints, 8 round, 133 lb, K-55
8 joints, 8 round, 94 lb, K-55
cross-over coupling, 8 round to buttress thread
7 joints, buttress, 94 lb, K-55

The top of the casing string was landed 0.8 m (2.7 ft) above KB. After being cemented to the surface, the casing was cut and welded to the landing base of the wellhead as shown in Fig. 28.

C. Intermediate Casing

The first run-in of the 34-cm (13-3/8-in.) intermediate casing was attempted on May 2, 1979, but a bridge at 672 m (2200 ft) prevented further penetration. The casing was pulled out and the hole cleaned and conditioned with high-viscosity mud. The next attempt on May 3 landed the casing at 761 m (2593 ft), which was about 30 m (100 ft) short of the design depth, but was still 27 m (90 ft) into the granitic basement rock. The casing consisted of:

Texas shoe
1 joint, short thread and coupling (ST&C), 61 lb, J-55
float collar
12 joints, ST&C, 61 lb, J-55
5 joints, ST&C, 54.5 lb, J-55
cement stage collar (Halliburton F0 external packer)
40 joints, ST&C, 54.5 lb, J-55

The casing was landed 1 m (3 ft) above KB; after being cemented to the surface, it was cut off flush with the top of the slips.

During drilling out of the cement plug, evidence of severe casing damage became apparent. Figure 28 shows the final landing depth of the casing shoe.

D. Production Casing

The final 24.5-cm (9-5/8-in.) production casing was run in without incident on March 28, 1980 to a predetermined depth of 3529 m (11 578 ft) in the 31.1-cm (12-1/4-in.) hole. The joint talley is shown in Fig. 28.

X. CEMENTING

A. Summary

Cementing operations in EE-2 were performed by both the Dowell and Halliburton field offices in Farmington, New Mexico. A summary of these operations is given in Table IX.

KB 8719.76 M. S. L. -

Fig. 28. EE-2 casing string and joint talley.

TABLE IX
SUMMARY OF CEMENTING OPERATIONS

Days After Spud	Amount		Remarks
	Mg	Sacks	
17	98.1	2300	Cemented 50.8-cm (20-in.) casing at 542 m (1780 ft) through stab-in float shoe: returns complete to surface, but 60 bbls suspected lost to LCZ; 2000 sacks Class H with 50/50 Pozmix, 2% gel, 40% silica flour; followed by 300 sacks Class H with 45% silica flour; Dowell.
26	8.5	200	Plug in LCZ above granite surface at 732 m (2402 ft); Class H neat cement through open-ended drill pipe; Dowell.
27	12.8	300	Second plug in LCZ at 732 m (2402 ft); Class H neat cement through open-ended drill pipe; Dowell.
30	12.8	300	Cemented first stage of 34-cm (13-3/8-in.) casing at 760 m (2493 ft); Class H cement with 40% silica flour; top wiper ruptured and all cement washed into LCZ; Dowell.
32	42.6	1000	Recemented first stage of 34-cm (13-3/8-in.) casing through Halliburton retainer at 735 m (2410 ft); Class H cement with 40% silica flour; Dowell.
32	42.6	1000	Cemented second stage of 34-cm (13-3/8-in.) casing through Halliburton FO external packer stage collar above the bottom of the 50.8-cm (20-in.) casing; Class H cement, 50/50 Pozmix A, 40% silica flour, 2% bentonite; Dowell.
43	59.7	1400	Cementing break-in casing at 721 to 725 m (2364 to 2380 ft); 400 sacks RFC, 1000 sacks Class H with 40% silica flour; Dowell.
51	12.8	300	Second cement plug for casing break at 726 m (2382 ft); Class H neat cement through open-ended drill pipe at 726 m (2382 ft); Dowell.

TABLE IX (CONT)

Days After Spud	Amount		Remarks
	Mg	Sacks	
53	25.6	600	Third cement plug into LCZ at casing break; Class H neat cement through Halliburton retrievable retainer at 465 m (1525 ft); Dowell.
57	93.8	2200	Fourth cement plug into LCZ at casing break; 200 sacks RFC, 1000 sacks Class H neat cement, 1000 sacks Class H with 40% silica flour through open-ended drill pipe; Dowell.
81	29.9	700	Fifth cement plug into LCZ at casing break; 200 sacks RFC, 500 sacks Class H neat cement through Halliburton RTTF packer at 460 m (1508 ft); Dowell.
163	25.6	600	Cemented break in 34-cm (13-3/8-in.) casing at 549 m (1800 ft); 200 sacks Class H cement with 12.5% Gilsonite and 1/4% Celloflake; 400 sacks Class H neat cement through open-ended drill pipe; Dowell.
278	4.3	100	Cemented collapsed casing at 549 m (1800 ft); Class H neat cement on top of burlap and sand plugs, through open-ended drill pipe at 548 m (1797 ft); Dowell.
279	4.3	100	Second cement plug for collapsed casing; Class B with thixotropic additive and 2% CaCl_2 on top of burlap and sand plugs, through open-ended drill pipe at 542 m (1777 ft); Halliburton.
279	4.3	100	Third cement plug; Class B cement with thixotropic additive and 2% CaCl_2 through open-ended drill pipe at 547 m (1796 ft); Halliburton.
280	4.3	100	Fourth cement plug; Class B cement with thixotropic additive and 3% CaCl_2 through open-ended drill pipe at 542 m (1796 ft); Halliburton.

TABLE IX (CONT)

Days After Spud	Amount		Remarks
	Mg	Sacks	
280	8.5	200	Fifth cement plug; Class B cement with thixotropic additive and 3% CaCl_2 placed in two 100 sacks slugs through open-ended drill pipe at 542 m (1796 ft); Halliburton.
281	8.5	200	Sixth cement plug; Halco light cement with 3% CaCl_2 , 12.5% Gilsonite and 1/4% Flocele in two 100 sacks slugs through open-ended drill pipe at 540 m (1790 ft); Halliburton.
283	8.5	200	Seventh cement plug; Class B cement with thixotropic additive, 12.5% Gilsonite and 1/2% Flocele through open-ended drill pipe at 546 m (1780 ft); Halliburton.
284	8.5	200	Eighth cement plug; Class B cement with thixotropic additive with 3% CaCl_2 , 12.5% Gilsonite and 1/2% Flocele, through open-ended drill pipe at 530 m (1765 ft); Halliburton.
301	8.5	200	Attempt to cement in alignment sleeve; Class H neat cement; Halliburton.
311	8.5	600	Sixth cement plug in LCZ at 716 m (2350 ft); 240 sacks Class B neat cement followed by 360 sacks with thixotropic additive through open-ended drill pipe; Halliburton.
316	17.1	400	Seventh cement plug in LCZ at 716 m (2350 ft); two slugs of 200 sacks each of Class B cement with thixotropic additive through open-ended drill pipe; Halliburton.
320	34.1	800	Eighth cement plug in LCZ at 716 m (2350 ft); 400 sacks with thixotropic additive followed by 400 sacks Class B neat cement through RTTF packer at 485 m (1590 ft); Halliburton.

TABLE IX (CONT)

Days After Spud	Amount		Remarks
	Mg	Sacks	
323	93.9	2200	Ninth cement plug in LCZ at 716 m (2350 ft) 200 sacks with thixotropic additive followed by 2000 sacks Class B neat cement through open-ended drill pipe at 27 m (90 ft); Halliburton.
324	14.9	350	Tenth cement plug in LCZ at 660 m (2165 ft); Class B neat cement through RTSS packer at 495 m (1623 ft); Halliburton.
326	----	-----	E-Z drill packer set at 530 m (1740 ft), but could not pump through it; packer drilled out; Halliburton.
329	8.5	200	Eleventh cement plug in LCZ at 660 m (2165 ft); Class H cement with 2% CaCl_2 through E-Z drill packer at 529 m (1735 ft); Halliburton.
347	4.3	100	Cemented sidetracked hole out of 34-cm (13-3/8-in.) casing; Class H cement with 2% CaCl_2 , 10% silica flour, 1% Flocele through open-ended drill pipe at 573 m (1880 ft); Halliburton.
349	2.2	50	Recemented sidetracked hole; Class H cement with 2% CaCl_2 , 10% silica flour, 5% Flocele through open-ended drill pipe at 572 m (1877 ft); Halliburton.
349	4.3	100	Ninth plug for collapsed casing; Class H cement with 2% CaCl_2 , 10% silica flour, 1% Flocele through open-ended drill pipe at 572 m (1877 ft); Halliburton.
349	2.2	50	Tenth plug for collapsed casing; Class H cement with 2% CaCl_2 , 10% Cal-Seal, 10% gel, 15% Fiberfil, 10% silica flour through open-ended drill pipe at 564 m (1850 ft); Halliburton.
350	10.7	250	Recemented sidetracked hole; Class B cement with 2% CaCl_2 , 10% Cal-Seal, 10% gel, 10% Fiberfil through open-ended drill pipe at 562 m (1845 ft); Halliburton.

TABLE IX (CONT)

Days After Spud	Amount		Remarks
	Mg	Sacks	
350	4.3	100	Recementing above sidetracked hole; Class B cement with thixotropic additive, with 2% CaCl ₂ , 10% silica flour through open-ended drill pipe at 498 m (1634 ft); Halliburton.
363	10.1	237	Cemented bottom 305 m (1000 ft) of 24.5-cm (9-5/8-in.) casing set at 3529 m (11 578 ft); Class H cement with 80% silica flour, 16.6 ppg; Halliburton.
Total	—	17 737	

Table X presents a summation of the quantity of cement used in each of the types of cementing activities. The initial cementing of the LCZ at 732 m (2402 ft) took only 500 sacks, but later cementing of this zone, occasioned by the break in the casing of May 16, required over 10 000 sacks.

B. Production Casing

The original design for cementing of the 24.4-cm (9-5/8-in.) production casing called for running the casing to approximately 3536 m (11 600 ft) and cementing to the surface in four stages, utilizing Halliburton F0 stage collars at 2438 m (8000 ft), 1524 m (5000 ft), and 607 m (2000 ft). The requirement for cementing to the surface was largely determined by the necessity to reduce the severe axial stresses in the casing string caused by cooling of the entire string to an injection water temperature of 40°C (104°F) during circulation of the underground loop. Also, because of this very cool operational mode, it was planned to cool the hole before cementing, and to maintain a temperature of 120°C (250°F) in the casing for 48 h after cementing, to allow the cement to set around a cooled and contracted casing string.

However, due to last minute developments and data acquisition, the procedure was revised to cement only the bottom 305 m (1000 ft); see Sec XIII, H for discussion.

A 31.1-cm (12-1/4-in.) bit with open jets was run in on 12.7-cm (5-in.) drill pipe to the top of the transition section to begin the precasing cool

TABLE X
SUMMATION OF CEMENTING QUANTITIES

	<u>No. of Sacks</u>
<u>Casing</u>	
50.8 cm (20 in.)	2300
34 cm (13-3/8 in.)	2300
24.5 cm (9-5/8 in.)	237
<u>Lost Circulation Zone</u>	
732 m (2402 ft)	500
<u>Casing Break -- May 16, 1979</u>	
34 cm (13-3/8 in.) casing at 732 m (2402 ft)	10 650
<u>Casing Collapse -- December 22, 1979</u>	
34 cm (13-3/8 in.) casing at 547 m (1800 ft)	2200
Total Sacks	<hr/> 17 737

down. Water was being hauled to the site at this time, as all circulation was being lost into the LCZ at the top of the granitic rock. Cool-down pumping continued at a rate of approximately 800 gpm from March 25 to March 28. The pipe was withdrawn and run in on the casing started. (Cementing hardware in the casing string is described in Sec IX, D.) With the casing landed at 3529 m (11 578 ft), cool-down flow through the casing was continued at rates of 500 to 800 gpm, lasting until March 31.

The cement slurry was preceded by 326 bbls of 16 ppg barite mud and 50 bbls of water. The bottom wiper plug was dropped at 10:45 am on March 31, followed by 75 bbls of Class H cement (with 80% silica) slurry. The top wiper plug bumped and held pressure at 11:40 am. As soon as possible, the drill string was run in open-ended, washing down to just above the top float collar at 3505 m (11 500 ft) to begin the postcementing cool-down. Circulation, with

returns through the 24.4-cm (9-5/8-in.) casing, began at 6:00 pm at a rate of 200 gpm and continued until April 3. The volume of cement slurry was calculated to fill the annulus to a depth of 3192 m (10 474 ft).

XI. LOGGING

Logging operations were performed in EE-2 largely to locate LCZs and to determine the integrity of the casing and cement backfill. Both Los Alamos-developed survey instruments and commercial tools were used.

A. Los Alamos Surveys

Temperature surveys conducted with Los Alamos National Laboratory instruments were used exclusively to locate LCZs or breaks in the casing, which could be identified by a sharp increase in temperature below the depth at which water flowed out of the hole. The spinner tool was also used to determine the relative amount of liquid exiting the hole at different depths. Both temperature and spinner surveys were run while water was being pumped down the hole, so that cold and moving water occurred above the LCZ or casing break, while hot, dead water existed below.

A three-arm caliper tool was also used to inspect the casing for breaks or changes in thickness.

The Los Alamos downhole TV camera was employed to identify the nature of the 34-cm (13-3/8-in.) casing collapse. The tool was also used to visually inspect the 24.4-cm (9-5/8-in.) production casing at 204 m (670 ft) to verify suspected wear reported by Dia-Log on May 9. Four passes of the camera at that depth revealed nothing unusual; however, a videotape of the casing between 168 m (550 ft) and 274 m (900 ft) was made for future reference.

B. Commercial Logging

Logging operations were performed by commercial logging companies as much as possible. Collar locator logs, caliper logs, and dual induction logs were used to examine the casing for possible defects; cement bond logs were run to determine the integrity of the cement backfill behind the casing.

Table XI lists all Los Alamos and commercial logs run while drilling EE-2. (Free-point determinations and associated collar locator logs are not included in this list.)

TABLE XI
LOGGING OPERATIONS IN EE-2

Days After Spud	Description
36	<u>Laboratory</u> ; temperature survey indicated LCZ at 731 m (2400 ft); through break in 34-cm (13-3/8-in.) casing.
37-38	<u>Schlumberger</u> ; caliper collar locator gamma Indication: casing separation between 742 to 753 m (2435 to 2469 ft) and a radioactive zone between 538 to 549 m (1766 to 1800 ft).
38-39	<u>Schlumberger</u> ; cement bond induction one-arm caliper collar locator Combined information revealed: buckled casing at 756 m (2480 ft), gaps at 751 and 742 m (2465 and 2434 ft), LCZ at top of granite, 732 m (2402 ft), damaged casing between 732 to 725 m (2402 to 2378 ft).
40	<u>Laboratory</u> ; temperature survey indicated casing breaks between 722 to 730 m (2370 to 2394 ft) and 742 to 752 m (2434 to 2468 ft).
42	<u>Laboratory</u> ; three-arm caliper from 518 to 777 m (1700 to 2550 ft); several runs to check casing breaks. <u>Laboratory</u> ; spinner, several runs to check casing breaks, pumping at 125 gal/min to 300 gal/min.
43	<u>Birdwell</u> ; collar locator three-dimensional velocity cement bond Indication: location of casing breaks uncertain. <u>McCullough</u> ; combined caliper and casing inspection, caliper tool failed Indication: excessive amount of metal where voids in casing were suspected.
46	<u>Schlumberger</u> ; cement bond gamma caliper collar Indication: confirmed previous surveys.

TABLE XI (CONT)

Days After Spud	Description
51	<u>Laboratory</u> ; temperature survey log to find LCZ; located at 726 m (2382 ft).
81	<u>Laboratory</u> ; temperature survey log to find LCZ; located at 732 m (2400 ft).
162	<u>Laboratory</u> ; temperature survey log to determine LCZ; located between 549 and 610 m (1800 and 2000 ft).
163	<u>Birdwell</u> ; caliper log indicated hole in casing at 548 m (1797 ft).
262	<u>Laboratory</u> ; temperature survey log to find LCZ; located at 723 m (2373 ft).
264	First TV run to examine collapsed casing; extensive damage at 530 m (1740 ft).
266	Second TV run; no clear picture because of murky water.
269	Third TV run; run down to 537 m (1763 ft); verified hole in casing at the FO stage collar, below that, the casing was oval shaped.
270	Fourth TV run; verified torn casing at 537 m (1762 ft). Splits in casing 0.6 cm (1/4 in.) x 8 cm (3 in.) seen between 537 and 544 m (1762 and 1783 ft); rubble seen through these splits. Large tear at 546 m (1792 ft), folded inward; split at 544 m (1783 ft) reveals top of 51-cm (20-in.) casing shoe.
271	Fifth TV run; aborted, water level at 439 m (1440 ft).
272	Sixth TV run; aborted, water level at 522 m (1711 ft).
277	Seventh TV run; to 540 m (1772 ft), halted by jagged metal pieces, shows further casing deterioration.
288	Eighth TV run; to 537 m (1763 ft), picture bad because of murky water in hole.
293	Ninth TV run; to 540 m (1772 ft), visibility zero due to muddy water in hole; attempts to circulate clear water and flocculate muddy water too time consuming.
296	Tenth TV run; to 356 m (1167 ft), displaced water with nitrogen, but unable to unload hole above 315 m (1035 ft), visibility bad because of foam in hole.

TABLE XI (CONT)

Days After Spud	Description
315	<u>Laboratory</u> ; temperature survey log to find LCZ; located below 709 m (2325 ft).
320	<u>Laboratory</u> ; temperature survey log to find LCZ; located at 725 m (2380 ft), small leak possibly at 549 m (1800 ft).
346	Eleventh TV run; rubble seen at 539 m (1770 ft), water encountered at 545 m (1788 ft), visibility very bad.
347	<u>Schlumberger</u> ; casing collar locator. dual induction Indication: last drill bit run (Bit #160) sidetracked out of 34-cm (13-3/8-in.)-diam casing at 561 m (1840 ft).
357	<u>Laboratory</u> ; temperature survey to 3534 m (11 588 ft) to determine hole temperature during precementing cool-down prior to running in the 24.4-cm (9-5/8-in.) casing.
361	<u>Laboratory</u> ; temperature survey to 3506 m (11 495 ft) to determine hole temperature during precementing cool-down after running in the 24.4-cm (9-5/8-in.) casing.
363	<u>Laboratory</u> ; temperature survey to 3355 m (11 000 ft) to monitor hole temperature during postcementing cooling.
366	<u>Dia-Log</u> ; 64-arm caliper survey to inspect casing, and obtain base-line measurements before continued drilling. Minor enlargement indicated at 3385 m (11 100 ft).
402	<u>Dia-Log</u> ; 64-arm caliper, inspection of 24.4-cm (9-5/8-in.) casing revealed thin spots at 204 m (670 ft) and 1978 m (6488 ft).
406	Twelfth TV run; from 274 to 168 m (900 to 550 ft) to visually inspect the 24.4-cm (9-5/8-in.) casing at 204 m (670 ft).
407	<u>Laboratory</u> ; three-arm caliper survey, confirmed thin section at 204 m (670 ft). <u>McCullough</u> ; magnetic inspection log, from 1981 to 2164 m (6500 to 7100 ft), to inspect lower casing.
408	<u>Laboratory</u> ; three-arm caliper survey to inspect casing.

XII. TUBULAR GOODS CHANGEOUT AND INSPECTION

A. Drill String and Accessories

The 31-cm (12-1/4-in.) intermediate borehole from 770 m (2463 ft) to the angle built point of 3.6 km (11 600 ft) measured depth was drilled with a string of 20-cm (8-in.)-o.d. drill collars until the torsional drag (measured at the surface) approached the make-up torque of the 13-cm (5-in.)-o.d. NC50 connections on the drill pipe and the axial drag approached the tensile strength of the 13-cm (5-in.)-o.d. drill pipe string (API premium used). At this point, essentially all drill collars were replaced with a string of 13-cm (5-in.)-o.d. HWDP drill pipe. The same HWDP string was used for bit loading for the drilling of the 22-cm (8-3/4-in.) slant portion of the hole; a 30% reduction in axial and torsional drag was realized.

In addition, to further reduce the magnitude of axial and torsional drag between the drill string and the borehole, a procedure was developed to alleviate the problem with a lubricant added to the drilling fluid (see Section V, drilling media).

As the torsional drag approached 5 to 10 revolutions of drill string twist, the capability to successfully manipulate torsionally responsive mechanical-drilling jars rapidly degraded. The mechanical jars were therefore replaced with a set of axially responsive hydraulic drilling jars (supplied by Houston Engineering Division, Wilson Industries), that incorporated several high-temperature features that allowed their use for the remainder of the drilling operations.

In an effort to reduce the effect of abrasive wear of the drill string by the granite borehole, a rigorous program of wear monitoring and repetitive application of sacrificial tungsten carbide hard-facing was instituted.

Inspection of casing and drill pipe (including BHA collars, crossover subs, shock absorbers, etc.) was done as described below in Table XII.

B. Casing

1. Conductor pipe; 71 cm (28 in.): no inspection.
2. Surface casing; 50.8 cm (20 in.): threads and grade inspected visually by GSM drilling manager.
3. Intermediate casing; 34 cm (13-3/8 in.): threads and grade inspected visually by GSM drilling manager.

TABLE XII

MAJOR DRILL PIPE INSPECTION SCHEDULE

<u>Date</u>	<u>Days Since Spud</u>	<u>Depth m (ft)</u>	<u>Reasons/Remarks</u>
6/18/79	76	1321 (4333)	Twist-off at 1152 m (3780 ft).
8/8/79	127	2736 (8975)	Routine inspection.
9/15/79	165	3068 (10 067)	Twist-off at 1387 m (4549 ft); replace with Grade E and S135 HWDP.
12/16/79	257	4163 (13 657)	Routine inspection.

4. Production casing; 24.4 cm (9-5/8 in.): all casing bodies inspected by Tuboscope's Amalog IV service; special end area inspection by cleaning, visual, and Magnaflux; the bottom 305 m (1000 ft) was sandblasted before inspection.

All pieces were numbered as they were laid out on the pipe racks and three separate strap lengths were obtained before being run in.

C. Drill Pipe

1. Inspection

Numerous washouts and twist-offs occurred in the drill collars, which initiated inspections of BHA boxes and pins at more frequent intervals than listed above. These frequent inspections consisted of Magnaflux testing on the rotary floor.

Drill string failures occurred in 12.7-cm (5-in.) nominal o.d., 19.5 lb/ft, Grade E drill pipe, and all occurred within 51 cm (20 in.) of a tool joint or connection. Inspections consisted of Tuboscope's Amalog IV service, with visual and Magnaflux inspection of boxes and pins.

2. Hard Banding

Below 2134 m (7000 ft), the routine hard banding of drill pipe tool joints became necessary, as the hole deviation increased and abrasive wear from the formation began to decrease the metal thickness. Hard banding by Tuboscope was performed every 125 to 150 rotating hours.

D. Cemented-In Casing Inspection

After the 24.4-cm (9-5/8-in.) casing had been cemented in, an account of trips and rotating hours was kept so that routine inspections could be made to prevent a second casing collapse problem. On May 9, after 31-1/2 round trips and 230 rotating hours on the production casing, Dia-Log ran a 64-arm caliper casing log. Thin spots at depths of 204 m (670 ft) and 1978 m (6488 ft) were indicated, and later verified by a Laboratory caliper survey and a magnetic inspection log by McCullough.

XIII. CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

From the experience that was gained from planning, supervising, and executing the drilling of hole EE-2, and from close association with developing the tools and equipment that made the completion of the hole possible, a number of conclusions and recommendations can be made that may be useful as guides in drilling similar holes. The problems in each of the major work categories, described previously in this report in a historical sense, are discussed in this section, together with a recommendation for preventing their occurrence.

A. Drilling Plan

The original drilling plan called for drilling to a temperature of 275°C (525°F). All design considerations for tools and hardware was based on the geothermal gradient (as determined in holes GT-2 and EE-1) producing that temperature at a true vertical depth (TVD) of 4265 m (14 000 ft). Bottom-hole temperature surveys were not conducted during the last few months of drilling, and it was only after the hole was completed at a TVD of 4493 m (14 750 ft) that surveys indicated the actual bottom-hole temperature to be about 320°C (608°F). While this higher temperature is certainly acceptable from a power/energy standpoint, it created problems (unknown at the time) with bit life, directional surveys, logging cables, jars, and lubricating fluids.

Recommendations. Frequent temperature surveys while drilling in an unknown reservoir would give indications of potential hardware/tool failures.

B. Drilling History

1. Contractural Agreements-Drilling. The choice of the Brinkerhoff-Signal Rig No. 56 proved to be an excellent one. This drilling rig had the best safety record, showed the most footage drilled and produced the most profit of any of Brinkerhoff's rigs in the Rocky Mountain region. The

crews were excellent, with very little turnover. Most of the personnel lived and maintained homes in the immediate area, which greatly contributed to the good drilling record.

Recommendation. Hire local personnel for best performance.

2. Contractural Agreements

a. Third Party. The contract item for subcontractor-acquired property and services provided for procurement of reimbursable items and services under a third-party agreement. Under the agreement, needed items and services could be procured via a telephone call and charged to the drilling contractor, who in turn submitted verified invoices for reimbursement. These invoices were often submitted several months after the arrival on site of the equipment or services. Very poor cost accounting procedures by the owner resulted in much confusion over the ongoing cost of the well; incomplete equipment lists resulted in paying rent on items longer than necessary.

Recommendation. A full-time employee is needed to keep track of costs, rental equipment, and third-party invoices.

b. Drilling Managers. The complexity of the operation was underestimated by the consultant firm in supplying qualified drilling managers. Personnel with the necessary technical backgrounds, as well as experience in geothermal work, were not available during the early months of drilling.

Recommendation. Drilling managers, furnished by the consulting firms, should be experienced in API-approved field practices regarding drill-rig operations. It is preferable that all drilling managers be degreed petroleum engineers or the equivalent, and have experience in drilling deviated, hot holes.

3. Drilling Progress. Both the drilling history diagram (Fig. 7) and the drilling activities diagram (Fig. 8) show that nearly 30% of the elapsed time was spent in fishing the twist-offs (6%) or repairing collapsed casing (23%). These costly delays could have largely been prevented by early detection of imminent failure by the presence of a geothermal logging/monitoring contractor on site. Although it was expected that the drilling managers could watch for signs of failure, it proved to be humanly impossible to supervise and direct such a complex drilling operation and still pay attention to the small details that might predict trouble.

Recommendation. Hire a reliable monitoring firm, in addition to the drilling managers.

C. Drilling Media

Although no noticeable problems arose during the drilling operations from the continued use of Baroid's Torq-Trim to increase lubricity while drilling in the deviated hole, problems did occur after the drilling rig was skidded to the adjacent hole. Oxidation of the Torq-Trim (triglyceride base) caused the formation of a sticky "black gunk" that coated the borehole walls below about 2750-m (9000-ft) depth. This substance interfered with logging and later fracturing operations, and necessitated cleaning with a workover rig.

Recommendation. Thoroughly clean the hole before moving the drilling rig off.

D. Drill Bits

The following criteria have been established at identifying lengths of bit runs that are considered to be characteristic of very good performance in crystalline granitic basement:

Rotary drilling; above 3353 m (11 000 ft), hole deviation $<30^\circ$: 91 m (300 ft)

Rotary drilling; below 3353 m (11 000 ft), hole deviation $<30^\circ$: 61 m (200 ft)

Motor drilling: 30 m (100 ft)

Bit runs that exceed this performance were picked out of the drilling record and a summary is presented below (Tables XIII and XIV).

Three cone, TCI bit performance while drilling with a downhole motor was predictable, although disappointing. Severe gauge wear at the higher rotational speeds (350 to 500 rpm) greatly restricted the useful life of motor-driven assemblies. For comparison, minimum cost per foot rotary drilling was obtained by operating IADC code 635 bits at high-energy levels. Typical operating parameters of 5500 to 6500 lbs of bit load per inch of bit diameter, 65 to 75 rpm rotary speed and 4.5 to 5.5 hydraulic horsepower per square inch of bit area resulted in penetration rates of 22 to 24 ft/h and maximum bit life of 30 to 40 h.²⁴

A special geothermal three-cone rock bit was used to great advantage almost exclusively to drill the 22.2-cm (8-3/4-in.) hole. This bit, manufactured by Smith Tool Company, is identified by the code type 7GA, and is

TABLE XIII
ROTARY DRILLING BIT PERFORMANCE

<u>Bit No.</u>	<u>Size</u>	<u>Make</u>	<u>Type</u>	<u>Depth Out</u>	<u>Footage</u>	<u>Hours</u>	<u>Deviation</u>
17	12-1/4	Sec	H-100	2,999	358	48.75	1/2°
RR28	12-1/4	STC	F-9	4,855	493	53.25	6°
34	12-1/4	Sec	H-100	5,892	345	24.00	7-3/4°
35	12-1/4	HTC	J-55	6,492	600	22.75	5-1/2°
45	12-1/4	HTC	J-55	7,689	505	21.75	6°
47	12-1/4	HTC	J-55	8,204	461	23.75	15°
55	12-1/4	STC	F-5	8,975	308	23.75	-----
104	8-3/4	STC	7GA	12,521	214	13.50	35°
105	8-3/4	STC	7GA	12,728	207	13.50	34°
117	8-3/4	STC	7GA	13,955	298	22.00	35°
138	8-3/4	STC	7GA	14,189	233	23.00	34-1/2°
137	8-3/4	STC	7GA	14,501	312	33.50	35°
140	8-3/4	STC	7GA	14,962	462	42.00	35°
142	8-3/4	STC	7GA	15,273	307	22.50	35°

TABLE XIV
MOTOR DRILLING BIT PERFORMANCE

<u>Bit No.</u>	<u>Size</u>	<u>Make</u>	<u>Type</u>	<u>Depth Out</u>	<u>Footage</u>	<u>Hours</u>	<u>Deviation</u>
41	12-1/4	Sec	H-100	6,818	100	12.25	4-3/4°
52	12-1/4	STC	Q9JL	8,545	131	3.00	13-3/4°
59	12-1/4	STC	Q9JL	9,188	106	3.00	-----
60	12-1/4	STC	Q9JL	9,311	123	3.00	13-1/2°
74	12-1/4	STC	Q9JL	10,035	118	5.50	-----

a nonsealed, jet circulation, TCI bit. Several special features that account for its superior performance are

- harder carbide buttons on the gauge row of the cones,
- hard facing for extra wear resistance on the leg shirt-tails,
- wear pad build-up and carbide inserts on the shanks of the legs,
- elimination of the seals that would deteriorate at temperature, and
- additional clearance in the bearings to allow for more circulation.

TABLE XV
SUMMARY OF EE-2 7GA BIT RUNS

<u>Bit Run No.</u>	<u>7GA Run No.</u>	<u>Ft</u>	<u>Serial No.</u>	<u>Condition</u>
106	1	214	AF 2308	8-8-I
107	2	207	AJ 0034	8-8-I
108	3	120	AJ 0035	4-8-I
110	4	164	AF 2337	2-2-I
111	5	36	AJ 9695	2-8-I
112	6	0	AL 0735	2-6-I
113	7	127	AF 4331	4-4-1/16
116	8	164	LF 4329	4-4-1/8
118	9	298	AF 2307	8-8-1/16
138	10	318	AP 9363	2-2-I
139	11	233	AP 96698	7-3-1/16
141	12	462	AF 2305	Dull
143	13	307	AP 9668	Lost Cone
144	14	0	AJ 0033	Run as BHA for Multi-shot Survey
145	15	15	HJ 0036	Turbodrill Test

These improvements increased downhole bit life (and reduced the number of trips from the deeper portions of the hole) to more than offset the 10% additional cost of the bits. A summary of all the 7GA bit runs is presented in Table XV.

Recommendation. For rotary drilling the 31.3-cm (12-1/4-in.) hole at depths of less than 3353 m (11 000 ft), Hughes J-55 bits gave excellent performance; for rotary drilling below that depth in the 22.2-cm (8-3/4-in.) hole, the Smith 7GA bits were unequaled.

During motor drilling operations, all in 31.3-cm (12-1/4-in.) hole, the Smith Q9JL bits gave superior performance.

E. Coring

Obtaining sufficient amounts of core from HDR boreholes is essential in determining a number of reservoir parameters. The need for this information is not encountered in either oil or gas wells or in conventional geothermal systems. Some of the more obvious items of information to be derived from core samples are:

- existence and orientation of natural fractures;
- nature of fracture filling minerals, if any;
- rock structure and fiber as it might affect hydraulic fracturing;
- rock type and age;
- rock porosity and permeability;
- core orientation by paleomagnetism;
- acoustic and velocity values;
- rock-water interactions;
- circulating fluid chemistry, as it might affect scaling or fouling of heat exchanger tubing;
- calibration of geophysical logging tools; and
- future bit design.

1. Bits. After the EE-2 coring runs had been completed, Smith Tool conducted an evaluation on 5 of the 20-cm (7-7/8-in.) hybrid core bits. Smith Tool rated the bearings, cutting structure elements, and the O-ring seals, Table III.

Smith Tool rated the bearings and the cutting structure elements on a scale of 1 (new) to 8 (ruined). The bearings were graded from 3 to 8. Before the seal failed, both the radial and thrust bearing surfaces appeared to be in excellent condition. The wear patterns were very uniform, indicating an

excellent load distribution. Overheating, however, was evident from a "bluish" discoloration on both the cone and journal bearing surfaces. After the seal failed, the bearings deteriorated quickly in the form of heavy scoring, spalling, and extrusion of the cone bearing material into the seal gland. This was followed by spindle bearing let-down and heavy out-thrust wear. Broken Stratapax studs were the major factors causing the out-thrust wear. The broken studs allowed the nose of the cones to ride directly on the formation, which increased the bearing loads dramatically. Overall, Smith Tool rated the bearing performance as very good.

Smith Tool also rated the overall appearance of the cone cutting structures as very good. The structures were rated from 1 to 4 and no excessive wear was noted. Smith Tool felt that the wear on cones graded 4 was perpetrated by bearing and seal failures. They indicated that this type of wear is typically caused by the bearings locking up intermittently, thus skidding the cutting structure on the formation.

Smith Tool examined the O-ring seals and reported an "unusual wear pattern." They felt the wear was not at all like the uniform abrasion usually encountered because the surface material appeared to have been torn away in small chunks or flakes. The hardness of the O-rings was discovered to be 5 to 8 points above the maximum allowed, indicating that the rings were exposed to higher than normal temperatures.

Smith Tool, based on their analysis, concluded that the major problem areas were the Stratapax studs breaking (Fig. 23) and the higher-than-expected seal temperatures.

Recommendation. The hybrid core bits performed well and are the first choice for future coring operations in crystalline, abrasive rock.

2. Core Barrels. A Hycalog 15.9-cm (6-1/4-in.)-o.d. X 4.5-m (15-ft)-long core barrel with stabilizing ribs for the 22.2-cm (8-3/4-in.) hole was used for all coring operations. The Hycalog service representative served as drilling engineer (and driller) during coring runs. On Core Run No. 2 and 6, core scribes were installed for orientation purposes, and on Run No. 7 as an internal core stabilization aid. After coring, the scribes were found to be either broken or worn completely down, with no scribe marks appearing on any of the core. On Core Run No. 2, during which no core was recovered because of drilling in a soft altered zone, it was felt that the core spring was too stiff to catch the friable core from this zone.

Recommendation. The Hycalog core barrel worked well, but improvements are needed in scribes for abrasive rock; also, for coring in friable zones, special core springs are available that are more suitable to retain the fragmented rock.

3. Core Orientation Tools. Orientation of the cores was not obtained for two reasons: (a) the scribes did not work, and (b) the core orientation tools failed. The first tool failure occurred because of overheating, despite the fact that a heat shield was used; the second failure occurred because the overshot grapple on the wireline recovery mechanism came unscrewed and before the tool could be withdrawn, the film suffered excessive heat damage. This last type of failure was a common occurrence in the wireline recovery of single-shot tools. Evidently, the thin-walled box connection of the wireline over-shot socket expanded more rapidly than the pin-end of the tool, which caused the connection to become loose. Vibration during the trip in and out caused the joint to completely unscrew.

Recommendation. Further improvements in heat shields need to be made. To avoid the unscrewing problem, a set screw or joint locking material could be utilized.

F. Directional Drilling

Well EE-2 was drilled from surface to an approximate KOP of 2141 m (7000 ft) TVD. Wellbore deviation and directional walk maintained a stable trend of less than 2° at NWW until the well was unintentionally sidetracked in a SWW direction at a depth of about 700 m (2500 ft). Inclination subsequently increased from 4° to 9° , primarily as a result of the running of weak build assemblies (Figs. 29, 30, and 31).

A series of motor-driven deflection runs were performed below 2141 m (7000 ft) to bring the wellbore course to a northeasterly direction. Following the successful azimuth alteration, attempts were made with various rotary-driven weak- and moderate-build assemblies to increase the wellbore deflection from vertical. These attempts were hampered by moderate-to-severe left walk tendencies, which necessitated periodic motor-driven corrections to maintain a northeast well course. Utilizing strong rotary-driven build assemblies, the desired inclination of 34° from vertical was achieved at approximately 3444 m (11 300 ft) TVD.

After reducing hole size, the EE-2 inclination was locked in at very near 34° inclination using strong-to-moderate packed hole assemblies. The hole course exhibited slight-to-moderate left walk to 3600 m (11 800 ft) TVD. Below

this depth the walk tendency reversed to the right at a slight rate and continued to the final TVD of 4496-m (14 750-ft) depth.

Figures 29 and 31 illustrate the performance of various rotary and motor-driven assemblies for changing or maintaining azimuth and inclination in the EE-2 granite borehole. The important points to be derived from these data are listed.

- Motor-driven bent subassemblies were an effective means of changing borehole azimuth.
- A very strong build assembly was required to obtain even a reasonable rate of inclination increase using rotary methods.
- Moderate packed hole assemblies were effective at maintaining inclination.
- Higher buildup rates were realized as inclination from vertical increased.
- Walk rate was difficult to control while using rotary-driven angle building assemblies.
- The effect of azimuth orientation on the buildup rate in Well EE-2 was minor.
- The tendency of the EE-2 borehole to walk or change azimuth is reduced at higher inclinations for both buildup and hold assemblies.
- The direction and rate of walk appears to be a function of both depth and azimuth orientation.

Many of the directional drilling obstacles and related problems were solved by the application of conventional techniques using available equipment and instrumentation. However, modifications became necessary as rigorous demands on these tools and techniques increased.²¹ In particular, modifications to conventional drilling techniques and equipment are necessary,

Fig. 29. EE-2 inclination and direction vs depth.

Fig. 30. Build-up rate and walk rate vs depth.

especially as drilling proceeds below 3048 m (10 000 ft), temperatures exceed 200°C (400°F), and borehole inclination approaches 35° from vertical.

New equipment developments were also necessary to perform the directional drilling in EE-2. Most important was the design and fabrication of a high-temperature, all metal Maurer turbine downhole motor capable of withstanding borehole temperatures hotter than 200°C (400°F). A rpm indicator also was developed to optimize turbodrill operation. Additionally, high-temperature shock absorbers were developed to reduce vibration and shock loads and to prolong the life of the downhole motor bearings. Both shock absorber tools developed for use below the downhole motor experienced seal failures as operating temperatures approached 193°C (380°F). Motor runs that were performed without the shock absorber subjected the steering tools to intense vibration and shock, resulting in extensive damage to tool components. Directional surveying techniques and equipment also required modification to allow measurements used to monitor directional drilling.

Fig. 31. Walk rate vs inclination, influence of BHA.

The controlled change in azimuth of the wellbore is the most difficult drilling operation and requires a continuous monitoring of the orientation of the BHA. This is necessary because variations in reaction torque are experienced by the drill motor as the lateral load is applied or drilling characteristics of the rock change. These reaction torques cause variable twist in the drill pipe and must be detected and corrected to hold the desired downhole orientation as drilling progresses. It is also important to restrict doglegging to less than 2° to 4° change per 30 m (100 ft) drilled. All azimuthal angle changes were performed with the typical BHA assembly listed in Table VIII.

Most of the problems that were encountered during directionally drilling EE-2 had been anticipated. Most are related to the hard abrasive rock and the high temperature.²³ Figure 32 depicts the temperature limitations of various components of the BHA and of other downhole equipment and hardware.

Major difficulties were:

- Single shot surveys failed because of high temperatures.
- Steering tools, including cablehead and wireline, failed because of vibration and high temperature.
- Limited bit life, and severe gauge wear required borehole reaming.
- Occasional doglegs required additional reaming.
- During inclination angle build, wander of the azimuth angle occurred requiring additional directional runs.

- Limited reamer/stabilizer life resulted in loss of tangency in inclination buildup.
- Float valve failures caused downhole motor plugging.

Of the three different types of motors used, only one, the Maurer turbodrill, demonstrated the capability to operate successfully above 200°C (400°F). Both of the positive displacement motors suffered thermal degradation of the stator. The turbodrill (run unsealed) suffered considerable radial bearing wear caused by high lateral bit loads aggravated by the additional length of the shock absorber below the motor and by the use of bent subs greater than 1-1/2°. As evidenced in Table VI, all motors provided acceptable penetration rates. Downhole life was limited by severe bit gauge wear to only two to three operating hours however.

Of the three different types of steering tools used on EE-2, only one, the Scientific Drilling Controls steering tool (run without a heat shield) displayed the capability to perform reliably at temperatures above 200°C (400°F). Many of the other steering tool failures can be attributed to cablehead and wireline problems. Motor runs performed without the shock absorber subjected the steering tools to intense vibration and shock resulting in extensive damage to tool components.

Both shock absorber tools developed for use below the downhole motor experienced seal failures as operating temperatures approached 193°C (380°F).

The pressure pulse turbine speed indicator performed satisfactorily to the maximum depth to which it was run, approximately 3048 m (10 000 ft).

Roller reamers were used as wall contact tools for all stabilized assemblies after earlier attempts to use fixed blade and pad type stabilizers gave very poor wear performance. The reamers significantly reduced torsional drag and exhibited increased effective BHA life. Although roller reamers provided less wall contact area than stabilizers, satisfactory directional control was realized.

Three major conclusions can be derived from directionally drilling EE-2. The first is that conventional directional drilling motors, wireline steering tools, shock absorbers, single shot surveying tools, bits, stabilizers, and many other associated equipment items are not directly applicable to high-temperature environments similar to those at Fenton Hill. Secondly, equipment capable of successful performance in such drilling environments has been developed and tested. And, thirdly, additional directional drilling

system developments are required to increase operational efficiency and reduce HDR drilling costs.^{23,24}

G. Casing

Casing problems accounted for the single largest percentage of nonproductive time, about 35% (see Fig. 8).

Problems occurred early with the placement of the 50.8-cm (20-in.) casing. After the first attempt at run-in, a mismatch between casing and coupling threads was discovered; damage to the casing joint threads by mismatched coupling threads could have accounted for the later collapse of the 50.8-cm (20-in.) casing.

When the 34-cm (13-3/8-in.) casing was run in, there was a question of the joint count, and later complications resulting from not knowing where the casing shoe actually was set. Rupturing of the casing due to this improper setting contributed to many later lost circulation problems, and the long casing collapse remedial work during the winter of 1980.

Recommendation. One drilling manager was on-site on a 24-h basis during the times these problems occurred. He could not possibly cover all the details that required attention to prevent them from happening. At least two drilling managers, or a geothermal logging and inspection contractor, are required.

H. Cementing

The casing cementing jobs were generally well planned and executed, except for hardware failures, by both Dowell and Halliburton.

1. Lost Circulation

Many of the early LCZ cementing attempts contained silica flour, which was probably unnecessary. The most effective LCZ cement jobs were large size, containing 800 to 1000 sacks of a thixotropic mixture followed by neat cement.

Recommendation. Don't waste time with small-scale attempts to seal off large-volume LCZ's.

2. Production Casing

The criteria that influenced the last-minute cementing design are as follows.

- It was necessary to install the casing in the least amount of time, while pumping without returns.
- Failure of the F0 stage collars to function above temperature of 163°C (325°F) as experienced in the Cerro Prieto geothermal field in Mexico was probable.

- Pilot test data on cement slurry indicated a tensile strength of 387 psi after curing for 72 h at 60°C (140°F).
- Numerous intervals of dogleg severity below 2743 m (9000 ft) might cause nonuniform circumferential loading of casing and result in buckling.
- Even though a 61-m (200-ft) length of cement sheath was adequate, a 305-m (1000-ft) length was selected as desirable for additional length to resist water leakage.

Recommendation. By keeping the cementing procedure simple, the chances for success were enhanced; in addition, a savings of approximately \$300 000 was realized. The amount of axial stress was significantly reduced by providing some lateral support, but allowing the casing to relax axially as thermal stress was applied.

I. Logging

The higher-than-anticipated temperatures made the procurement of commercial logging services very difficult. Also the presence of the "black gunk" made later logging efforts very difficult. A gyro survey by Sperry-Sun was accomplished in August 1980 (see Fig. 33), which corroborated with the single shot surveys obtained by Eastman-Whipstock.

Recommendation. High-temperature survey tool and logging cable development is urgently needed.

J. Tubular Goods Inspection

1. Casing

Serious problems occurred with both the 50.8-cm (20-in.) and 34-cm (13-3/8-in.) casing shortly after run-in. Both of these strings had received only a visual thread inspection, and no double checking of the strap lengths. The collapse of both casing strings may have resulted from the lack of nondestructive inspections.

Recommendation: All casing bodies should be inspected for internal defects, in addition to special end area inspections, and at least a double check of strap lengths.

2. Drill Pipe

In consideration of the hostile environment to which it was exposed, drill string performance was remarkably good. The most unfavorable factor was the rapid abrasive wear of the drill string. Although no downhole failures were attributed to this abnormal wear, some 1219 m (4000 ft) of drill pipe had to be discarded or downgraded due to external wear. Repeated application of

Fig. 32. Temperature limitations of downhole hardware and equipment.

ALL DEPTHS TRUE VERTICAL BELOW KB SINGLE SHOT SURVEY GYRO SURVEY

Fig. 33. Comparison of single shot and gyro surveys in EE-2. All depth true vertical depth below KB .

tungsten carbide hard banding on the tool joints was used to retard the wear rate. Two downhole fatigue failures of the drill string occurred. Both of these failures were attributed to fatigue crack growth from deeply penetrating, sharp, corrosion pits. This low incidence of fatigue failure in consideration of the length of directional hole and the magnitude of axial and torsional loading cycles applied to the drill string, is due in part to the careful attention paid to the avoidance of high dogleg severity in the upper hole and to the use of low yield strength (75 000 psi) drill pipe for all but the upper 1067 m (3500 ft) of the string.

Drill pipe failures, including washouts and twist-offs, were analyzed and reported upon by A. Kumnick of the Laboratory (Appendix H). The twist-off at

1368 m (4549 ft) occurred while starting to trip out from 3068 m (10 067 ft). The string load was approximately 310 000 lbs, with about 900 rotating hours on the string. The twisted-off pin end was sent to Radian Corporation in Austin, Texas for analysis in their Failure Analysis Laboratory under DOE Contract DE-AC03-81SF11503. Appropriate sections of their report are extracted below.

"The sample had extensive pitting 0.079-0.090 in. deep on the inside diameter surfaces with a white deposit covering the pits. X-ray diffraction of these deposits indicated that most of the deposit was amorphous. However, the crystalline species magnetite (Fe_3O_4) was identified, as well as traces of calcium sulfate hemihydrate ($\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$). No indications of calcium sulfate species were found.

Wall thickness measurements were made at 12 random points. Within 95% confidence limits, the mean wall thickness of the piece is 0.341-0.373 in. Information supplied with the pipe, in combination with maximum measured thicknesses, indicates that the original wall thickness was 0.500 in.

Close-up photographs of the piece show that the inside diameter surface was extensively pitted. Fatigue striations are evident on the fracture surface. These striations have initiated from the inside diameter pits.

The cause of inside diameter extensive uniform corrosion and pitting, as well as the source of the deposits, could not be determined. This pipe was acquired used and was not inspected prior to use at Fenton Hill. Some or all of the pitting damage may have occurred prior to use in the HDR well. On the other hand, the HDR drilling water contained 116 ppm chloride as well as dissolved oxygen. At the elevated temperatures possible in the drilling operation this combination of chloride and oxygen, especially in conjunction with the inside diameter deposits may have caused significant pitting by an occlusion cell mechanism in the 900 h this pipe was in service.

Fractographic examination showed fatigue striations emanating from corrosion pits on the inside diameter. This

drill pipe ultimately failed by fatigue cracks which initiated at the bottom of inside diameter corrosion pits. The drilling water contained chloride, oxygen, and bicarbonates, all of which have been shown to promote corrosion fatigue in low alloy steels. Acidic pH's are also expected in the pits and such pH's favor corrosion fatigue.

Conclusion: This piece (with 900-h rotating service) failed by fatigue or corrosion fatigue initiated from inside diameter corrosion pits. However, the combination of aeration, temperature, chloride concentration, and presence of inside diameter deposits may have caused significant pitting by occlusion cell (or under-deposit) corrosion mechanism. This pipe also showed wall thickness reductions of about 0.150-0.200 in."

Recommendation: Inspect all drill pipe when it comes on location, and at periodic intervals of not more than 250 rotating hours, especially when drilling in deviated holes. Perform a mechanical-optical inspection on inside surfaces within 1 m (3 ft) of ends, with Analog IV or equivalent inspection on the pipe body and magnetic particle inspection on threads.

Perform hard banding as required to maintain box end thickness.

3. Cemented-In Casing

The collapse of the 34-cm (13-3/8-in.) casing was attributed to three possibly interconnected causes.

- (a) Many trips and rotating hours created thin spots on the inside.
- (b) When circulation was lost at the casing shoe, the unbalanced hydrostatic pressure on the outside of the casing exerted a collapse pressure.
- (c) A strong gamma response noted during the logging of May 12 at about (1800 ft) may have been an indication that a high-salt content aquifer existed there, which might cause corrosion on the outside.

Recommendation: Frequent caliper logs to determine wear points, and constant monitoring of fluid losses to prevent sub-hydrostatic pressures on the inside, might have prevented the collapse.

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APPENDIX A

DRILLING FLUID PROGRAM:

0-1,900'

WATER: 8.3-8.5 PPG
BENTONITE/LIME SWEEPS FOR HOLE CLEANING
CIRCULATE RESERVE PIT FOR SOLIDS CONTROL

1,900'-2,700'

WATER: 8.3-8.5 PPG
ANTICIPATE DRILLING W/NO RETURNS TO SURFACE
WILL REQUIRE 150,000 BBL WATER TO CASING POINT
BENTONITE/LIME SWEEPS FOR HOLE CLEANING

2,700'-14,500'

WATER: 8.3-8.5 PPG
BENTONITE/LIME SWEEPS FOR HOLE CLEANING
CIRCULATE RESERVE PIT FOR SOLIDS CONTROL
IF NECESSARY TO DIVERT RETURNS TO STEEL
PITS, UTILIZE SHAKER, DESANDER & DESILTER
CONTINUOUSLY.
INTERMEDIATE COOLING OF DRILLING FLUID WILL
LIKELY BE REQUIRED BELOW 11,000'

TUBULAR GOODS PROGRAM:

CONDUCTOR CASING: SET 100' 28" O.D. CASING AS FOLLOWS:
SEC. BOTTOM LENGTH WGT. GRADE CONN.
1 100' 100' 74.09 PPF X-42 WELD
CEMENT W/ 20 VOLS REDIMIX DOWN ANNULLUSSURFACE CASING: SET 1,800' 20" O.D. CASING AS FOLLOWS:
SEC. BOTTOM LENGTH WGT. GRADE CONN.
1 500' 500' 94.0 PPF H-40 BUTTRESS (ON HAND)
2 1,300' 800' 106.5 PPF K-55 ST&C
3 1,800' 500' 133.0 PPF K-55 ST&C
CEMENT W/ 1,800 SX HLC AT 12.7 PPG FOLLOWED BY
400 SX CLASS G AT 15.8 PPG. CEMENT DOWN DRILL
PIPE USING "INNER STRING" METHOD.INTERMEDIATE CASING: SET 2,700' 13.375" O.D. CASING AS FOLLOWS:
SEC. BOTTOM LENGTH WGT. GRADE CONN.
1 2,200' 2,200' 54.5 PPF J-55 ST&C
2 2,700' 500' 61.0 PPF J-55 ST&C
CEMENT W/ 300 SX RETARDED HLC AT 12.7 PPG FOLLOWED BY
250 SX CLASS G AT 15.8 PPG

PRODUCTION CASING: SET 12,000' 9.625" O.D. CASING

AS FOLLOWS:

SEC. BOTTOM LENGTH WGT. GRADE CONN.
1 4,000' 4,000' 40 PPF N-80 BUTTRESS
2 8,000' 4,000' 40 PPF K-55 BUTTRESS
3 12,000' 4,000' 40 PPF N-80 BUTTRESS
CEMENT W/ SWRI HYDROTHERMAL CEMENT. FORMULATION
AND PLACEMENT TECHNIQUE TO BE SPECIFIED.NOTE: PRODUCTION CASING WILL NOT BE SET UNTIL
COMPLETION INTERVAL IS DEFINED BELOW 11,000' GRACE, SHURSEN, MOORE & ASSOC.
AMARILLO, TEXASLos Alamos
scientific laboratory
at the University of California
48001 New Mex. 131015ENERGY EXTRACTION
WELL EE-2
JEMEZ PLATEAU
SANDOVAL COUNTY, NEW MEXICO

BIT PROGRAM *				HYDRAULICS **				COMMENTS				LITHOLOGY			
BIT NO.	ADC CODE	JETS	WOB	RPM	PUMP NO.	LINE SIZE	SPM	GPM	PRESS	BIT TOTAL	MIN. A.V.	HOLE SIZE			
1	111	3-26	MAX	100/150	1/2	7.5"	60/55	1186	838	301	580	44	28" CONDUCTOR SET AT ± 100'	VOLCANICS	
2	111	3-26	MAX	100/150	1/2	7.5"	60/55	1186	871	192	603	44	VOLCANICS GENERALLY UNCONSOLIDATED, FRIABLE & HIGHLY PERMEABLE. HIGH FLUID LOSS, HOLE ENLARGEMENT & CAVING HOLE.	ABO RED BEDS	
3	121	1-33	60/70	100/150	1/2	7.5"	60/55	1186	877	106	607	44	HYDRATABLE CLAYS. HOLE SLUGHING & SWELLING.	MADERA LIMESTONE	
4	121	1-25	60/70	100/150	1/2	7.5"	60/55	1186	873	19	604	44	TIGHT HOLE & BRIDGES VISCIOUS SWEEPS REQUIRED TO MAINTAIN CARRYING CAPACITY IN 26" ANNULUS.	SANDIA	
5	121	1-25	60/70	100/150	1/2	7.5"	60/55	830	1700	625	823	71	PRESSURE TEST 20" CASING PRIOR TO DRILLING OUT COMPLETE LOSS OF CIRCULATION AT ± 1,900'	GRANITIC BASEMENT	
6	131	1-17	60/70	100/150	1/2	7.5"	60/55	830	1636	575	752	71	DRY DRILLING PROCEDURES IMPLEMENTED		
7	131	1-17	60/70	100/150	1/2	7.5"	60/55	830	1636	575	752	71	PRESSURE TEST BOPS & 13-3/8" CASING PRIOR TO DRILLING OUT		
8	131	1-17	60/70	100/150	1/2	7.5"	60/55	830	1636	575	752	71	NOTE: ALL BASEMENT ROCK DISPLAYS LOW TO MODERATE DRILLABILITY AND IS HIGHLY ABRASIVE		
9	131	1-17	60/70	100/150	1/2	7.5"	60/55	830	1636	575	752	71	TEST INFLATABLE PACKER IN SHORT SECTION OF 8-3/4" HOLE PRIOR TO REACHING KOP		
10	837 (OR ON HAND 835)	2-9	60/70	40/60	1	5.75"	60	356	2592	501	538	67	PERFORM TURBODRILL OPERATIONAL TEST PRIOR TO KOP		
11	837 (OR ON HAND 835)	2-9	60/70	40/60	1	5.75"	60	356	2636	501	548	67	ESTIMATED KOP AT ± 9,570'		
12	837 (OR ON HAND 835)	2-9	60/70	40/60	1	5.75"	60	356	2680	501	557	67	BUILD UP AT ± 2°/100'		
13	837	1-3	60/70	40/60	1	5.75"	60	356	2415	436	501	67	REDUCE HOLE SIZE TO 8-3/4" AT 11,000' TVD		
14	837	1-3	60/70	40/60	1	5.75"	60	356	2459	436	511	67	REACH 30° INCLINATION BY 11,000' TVD		
15	837	1-3	60/70	40/60	1	5.75"	60	356	2489	436	517	67	DRILLING FLUID COOLING SYSTEM OPERATIONAL		
16	837	1-3	60/70	40/60	1	5.75"	60	356	2489	436	517	67	MAINTAIN ± 30° INCLINATION AT 2 N45 E		
17	837	1-3	60/70	40/60	1	5.75"	60	356	2489	436	517	67	ANTICIPATE CUTTING SIX(6) CORES BETWEEN 11,000' & 14,000' TVD		
18	837	1-3	60/70	40/60	1	5.75"	60	356	2521	436	524	67	TOTAL DEPTH ESTIMATED AT 13,500' - 14,000' TRUE VERTICAL DEPTH OR 200' C. BOTTOM HOLE STATIC TEMPERATURE		
19	837	1-3	60/70	40/60	1	5.75"	60	356	2549	436	529	67	DEFINE COMPLETION INTERVAL, OPEN RAT HOLE TO 12-1/4" & SET 9-5/8" CASING		
20	837	1-3	60/70	40/60	1	5.75"	60	356	2610	436	542	67			
21	837	1-3	60/70	40/60	1	5.75"	60	356	2635	436	547	67			
22	837	1-3	60/70	40/60	1	5.75"	60	356	2660	436	552	67			
23	837	1-3	60/70	40/60	1	5.75"	60	356	2682	436	557	67			
24	837	3-10	60/70	40/60	1	5.75"	60	356	2448	382	508	67			
25	837	3-10	60/70	40/60	1	5.75"	60	356	2465	382	512	67			

* REFER TO DETAILED ROCK BIT PROGRAM

** REFER TO DETAILED HYDRAULICS PROGRAM

APPENDIX B
DRILLING RIG INVENTORY
BRINKERHOFF-SIGNAL DRILLING COMPANY, INC.
RIG NO. 56

Drawworks

Continental-emsco A1100-E, double grooved drum with 1-1/4-in. drilling line, equipped with Parkersburg 46-in. rc hydramatic brake and National Micromatic automatic drilling control.

Power

Diesels -- Three Caterpillar D398 rated at 2727 total intermittent HP driving 3 DC generators and 1 AC generator.

Electrical -- Three GE 752 DC generators, and two 350 KW-AC 440-V generators sufficient for rig and camp.

Mud Pumps

1 -- Continental-Emsco F-1300, 1300 HP, triplex pump, with Continental-Emsco 3-in. shear relief valve, Continental-Emsco pulsation dampener, powered by two GE motors.

1 -- Emsco D-1000, 1000-HP pump.

Mast-Sub

142-ft Lee C. Moore cantilever mast; 1,025,000 lb GNC mounted on 27-ft high enclosed substructure. Substructure is modified with 13-ft extension forward to provide proper balance for raising and lowering mast.

Hook load with 8 lines strung -- 683 000 Lbs.

Hook load with 10 lines strung -- 703 000 Lbs.

Hook load with 12 lines strung -- 718 000 Lbs.

Rotating-Traveling

1 -- 27-1/2-In. Emsco Rotary Table

1 -- 300-Ton Emsco L300 Swivel

1 -- 400-Ton Block with BJ6350 Unimatic Hook

1 -- 1-1/4-In. Drilling Line

Pipe

5-In. Outside Diameter, 19.50 Lb and 25.60 Lb Grade E, 19.50 Lb Grade G with NC50 connections.

APPENDIX B (CONT)

BOP

- 1 -- 13-5/8-In., 5000 Lb, W.P. Shaffer Hydraulic Bag Preventer
- 1 -- 13-5/8-In., 5000 Lb, W.P. Shaffer LWS Double Hydraulic Ram Preventer (H2S trimmed)
- 1 -- 3000 Lb, 130-Gal, Koomey BOP Accumulator Closing Unit, with Nitrogen Back-Up Bottles
- 1 -- 6 Station, Koomey Control Unit at the Accumulator
- 1 -- 6 Station, Koomey Remote Control Unit on the Floor
- 1 -- 4-In., 5000 Lb, W.P. BOP Manifold with 1 Adjustable Choke
- Upper and Lower Kelly Cocks and Inside BOP

Mud System

- 1 -- 300 BBL Active Tank (includes 100 bbl Pill Tank)
 - 2 -- 350 BBL Reserve Tanks (700 bbl Capacity)
 - 1 -- 100 BBL Shaker-Settling Tank
 - 1 -- Shale Shaker, Brandt, Double Deck, Tandem
 - 1 -- Trough Tank with Top-Mounted 4 to 8 In. Cone Thompson Desander, 4T4
- SWACO Desilter

- 5 -- Lightnin' 5-HP Mud Mixers
- 4 -- 4-In. X 6-In. VacSeal Centrifugal Pumps Powered by 4-60 HP, AC 480-V motors

Instruments and Power Accessories

- 1 -- Varco Spinner Wrench
- 1 -- Automatic Driller, National Micromatic
- 1 -- Crown-O-Matic
- 1 -- Martin Decker Weight Indicator
- 1 -- Adjustable Stabbing Board
- 1 -- 10 000 Ft, 0.092 In., Measuring Reel Powered by Joe Stine Hydraulic

Winch

Heating

- 1 -- 100 HP Lister Steam Boiler
- 1 -- Tioga Air Heater with 2 Ft X 2 Ft Air Ducting, 2 100 000 Btu

APPENDIX B (CONT)

Miscellaneous

- 1 -- Lot of Rig Mats
- 1 -- Lot of Fire Extinguishers, First Aid
- Fuel Storage Tanks, 9000 Gal
- Totco 5-Pen Recorder
- Minimum 8° Survey Recorder
- 8 -- Triangular Pipe Racks
- 1 -- 500 bbl Water Tank

APPENDIX C
SUMMARY OF EE-2 BIT RUNS

Bit #	Size	Make	Type	Jets	Depth Out	Footage	Hours	Bit wt 1000#	#/dia Inch	RPM	Pump Pressure	Pump Rate GPM	HHP/in. ²	Deviation & Direction	MW	PV	BHA	Condition T B G	Remarks
1	26"	HTC	OSC 3AJ	22-22-22	604	524	60	5-25	Avg 577	60	825	566	0.14	1/2°	9.5	11	Bit, reamer, shocksub, stabilizer, 6-9" DC's, 5-8" DC's	4 4 1	Pulled to change BHA
2	26"	STC	DTJ	24-24-24	938	334	42	5-10	Avg 288	150	800	523	0.08	5°	10.3	18	" " " " " " " " " " " "	3 2 1	
3	26"	STC	DTJ	24-24-24	1259	432	52.5	20-45	Avg 1250	90	700	594	0.12	1-3/4°	9.9	16	Bit, shocksub, 2-9" DC's, stabilizer, 1-9" DC, stabilizer, 3-9" DC's, 5/8" DC's	4 8 1	
4	26"	HTC	OSC 3AJ	24-24-24	1729	470	56.75	35-50	Avg 1635	110	1100	1050	0.634	1/2°	9.6	17	" " " " " " " " " " " "	4 7 1	
RR#2	26"	STC	DTJ	24-24-24	1785	56	7.25	50	1923	110	700	621	0.133	-	9.7	16	" " " " " " " " " " " "	4 7 1	
Ran 20" Casing to 1780' KB																			
5	17-1/2"	Sec	S4T	open	1940	155	26	20-40	Avg 1714	90	400	432	-	0°	9.0	11	Bit, Shocksub, 1-8" monel, 1-9" DC, stabilizer, 1-9" DC, stabilizer, 4-9" DC's, 5-8" DC's	4 4 1	
6	17-1/2"	Sec	S-88	open	2295	355	46.5	50-55	Avg 3000	60-80	400	621	-	3/4°	9.4	15	" " " " " " " " " " " "	2 6 1	
7	17-1/2"	Sec	S-88	open	2463	168	19.5	55	3143	80	400	540	-	-	9.4	15	Bit, shocksub, 1-8" monel, 6-9" DC's, 3-8" DC's, jars, 2-8" DC's	3 6 1	Lost returns at 2354' RB
8	17-1/2"	Sec	H-8	16-16-16	2593	130	11.75	47	2686	80		432	0.43	1°	Water	-	" " " " " " " " " " " "	3 6 1	No returns - drilling granite
9	17-1/2"	Sec	S-89														" " " " " " " " " " " "		Ream hole - hole sloughing
Ran 13-3/8" casing to 2492' KB																			
10	12-1/4"	HTC	J-77	12-12-12											Water		Bit shocksub monel, 6-9" DC's, 5-8" DC's	3 3 1	Drill cement and retainer
11	12-1/4"	HTC	J-77	12-12-12	2619	26	4.5	50	4082		1050	432	2.78		"		" " " " " " " " " " " "		Lost all three nose cones in hole
12	12-1/4"	Sec	S3S	11-11-11	2400	612									"		" " " " " " " " " " " "		Drill cement
13	12-1/4"	STC	DTJ	11-11-11	2412	12									"		" " " " " " " " " " " "		Drill cement and junk in four runs
14	12-1/4"	STC	DTJ	15-15-15	2426	14									"		" " " " " " " " " " " "		
15	12-1/4"	HTC	J-77	16-16-16	2641	215	41.75	45	3673	50					"		Bit, shocksub, monel, 6-9" DC's, 5-8" DC's		Lost circulation through hole in casing - made 6 runs
16	12-1/4"	STC	DTJ	11-11-11			20.5								"		Bit, shocksub, monel, 6-9" DC's, 5-8" DC's		Drill cement 1360' to 2393'
17	12-1/4"	Sec	H-100	12-12-13	2999	358	48.75	50	4082	50	1800	324	2.65	1/2°S38E	"		Bit, reamer, shocksub, X-0, 8" monel, stabilizer, X-0, 6-9" DC's,		Drilling granite
18	12-1/4"	Sec	H-100	12-12-13	3258	259	36.5	50-55	Avg 4286	50	1800	324	2.65	3-1/2°S56W	"		Bit, bit sub, monel, X-9, stabilizer, 6-9" DC, 5-8" DC		Bit washed out in weld
19	12-1/4"	STC	Q9JL	12-12-13	3288	30	4.75	45-50	Avg 3878	50	1800	324	2.65	3°S64W	"		" " " " " " " " " " " "	4 4 1	
20	12-1/4"	Sec	H-100	12-12-13	3319	31	7	45-50	Avg 3878	50	1800	324	2.65	-	"		" " " " " " " " " " " "	1 2 1	Reamed out of gauge hole 3268' - 3318'
21	12-1/4"	Sec	H-100	12-12-13	3584	265	45.25	40	3265	68	1800	324	2.65	5°	"		" " " " " " " " " " " "	6 6 1/8	
22	12-1/4"	Sec	H-100	12-12-12	3827	243	35.75	38-50	Avg 3592	68	1800	324	1.17	5°	"		" " " " " " " " " " " "	7 7 1	
RR#20	12-1/4"	Sec	H-100	12-12-12	3920	93	16.25	35	2857	68	1800	324	1.17	5°	"		" " " " " " " " " " " "	4 6 1	Trip for washout
23	12-1/4"	Sec	H-100	12-12-12	4020	100	18	35	2857	68	1800	324	1.17	5-1/4°	"		" " " " " " " " " " " "	2 2 1	
24	12-1/4"	Sec	H-100	12-12-12	4233	213	34	35	2857	68	1800	324	1.17	5-1/4°	"		" " " " " " " " " " " "	6 6 1	Trip for washout. Drill string came in two while off bottom
25	12-1/4"	STC	F-9	11-11-11	4340	107	21.75	45	3673	65	1800	324	1.66	5-1/2°	"		" " " " " " " " " " " "		Milled on junk, left 2 RWP pads in hole
26	12-1/4"	STC	F-9	11-11-11	4340	0									"		" " " " " " " " " " " "		Mill on junk
27	12-1/4"	STC	Q9JL	11-11-11	4340	0									"		" " " " " " " " " " " "		
RR#23	12-1/4"	Sec	H-100	11-11-11	4345	5	5	20	1633	50	1800	324	1.66		"		" " " " " " " " " " " "		Lost returns
28	12-1/4"	STC	F-9	11-11-11	4362	17								5-1/2°	"		" " " " " " " " " " " "		Drill cement
29	12-1/4"	STC	DTJ	11-11-11											"		Bit, 4 DC's		
RR#28	12-1/4"	STC	F-9	11-11-11	4855	493	53.25	65	5306	68	2500	443	4.19	6°	"		Bit, RWP, RWP, 8" 5 DC, RWP, 7-8" DC's, RWP, 8" DC, RWP, 9" DC, X-0, 9" DC, Y-0, 9-8" DC	6 4 1/4	Turbo run
30	12-1/4"	Sec	H-100*	18-18-13	4912	57	3.75	30-35 Avg	2653	250-400	2200	478	1.66	5-3/4°	"		Bit, shocksub, turbodrill, X-0, 8" DC, RWP, X-0, 5-9" DC's, 9-8" DC's	8 8 3/4	
31	12-1/4"	Sec	H-100	14-14-13	5012	100	8.5	50-65 Avg	2653	75	2500	464	4.13	8°	"		Bit, 6 pt, RWP, shocksub, 8" 5 DC, IBS, 8" DC, IBS, 5-9" DC's, 9-8" DC's	4 2 1/16	
32	12-1/4"	STC	F-9	14-14-13	5260	248	19	60	4898	70-80	2100	464	4.13	8-1/4°S-82N	"		Bit, 6 pt, RWP, 8" DC, IBS, monel, X-0, 5-9" DC's, X-0, 10-8" DC's	8 4 1/16	
33	12-1/4"	Sec	H-100	14-14-13	5547	287	22.75	65	5306	75	2500	455	3.92	8°	"		Bit, 6 pt, RWP, 8" 5 DC, IBS, monel X-0, 5-9" DC's, X-0, 10-8" DC's	8 8 1/16	
34	12-1/4"	Sec	H-100	11-11-11	5892	345	24	65	5306	75	2450	445	4.29	7-3/4°	"		Bit, junk basket, 6 pt, RWP, 8" 5 DC, IBS, monel, RWP, 18-18" DC's	5 7 1/8	
35	12-1/4"	HTC	J-55	11-11-11	6492	600	22.75	63	5143	75	1500	353	2.14	5-1/2°	"		Bit, 6 pit, RWP, 8" 5 DC, RWP, monel, RWP, 19-8" DC's	7 5 1/2	

*Run with downhole motors.
HTC - Hughes Tool Co.
Sec - Security
STC - Smith Tool Co.
Reed - Reed Tool Co.

APPENDIX C (cont)

SUMMARY OF EE-2 BIT RUNS

Bit #	Size	Make	Type	Jets	Depth Out	Footage	Hours	Bit wt 1000#	#/dia Inch	RPM	Pump Pressure	Pump Rate GPM	HHP/in. ²	Deviation & Direction	MW	PV	BHA	Condition T B G	Remarks
36	12-1/4"	STC	F-9*	open	6518	26	2	10	816	400	750	404	-	4-1/2°	Water		Bit, DynaDrill, monel, 12 DC's	8 5 1/2	Dyna Drill
37	12-1/4"	Sec	H-100*	open	6546	46	1	10	816	400	600	325	-	4-1/4°	"		" " " " " "	3 4 1/8	Dyna Drill
38	12-1/4"	STC	Q9J*	open	6597	51		3-3/4	5	408	325	305	-	3°	"		" " " " " "	2 2 1/8	Dyna Drill
39	12-1/4"	Reed	S74	11-11-11	6619	22	2	50	4082	60	2000	394	2.97	3°	"		Bit, 6 pt, monel, RWP, 8" DC, RWP, 19-8" DC's	2 2 1/8	Ream 6492' - 6597'
40	12-1/4"	STC	Q9J*	open	6718	99	5-1/2	8-10 Avg	735	400	700	404	-	4°	"		Bit, Dyna Drill, float-sub, bent-sub, monel, 12-8" DC's	4 6 1/4	Dyna Drill
RR#39	12-1/4"	Reed	S74	11-11-11	6718	0													
41	12-1/4"	Sec*	H-100	12-12-12	6818	100	12.25	10-15	Avg 1020	178	1400	353	1.52	4-3/4°N37W	Water		Bit, Dyna Drill, float sub, bent-sub, monel, 11-8" DC's	4 2 1/16	Reamed 6590' - 6718'
RR#39	12-1/4"	Reed*	S74J	11-11-11	6869	51	3	45	3673	70	1450	353	2.14	4-1/2°N7W	"		Bit, 6 pt, monel DC, RWP, 14 DC's	8 4 1/16	Dyna Drill
42	12-1/4"	STC*	Q9JL	12-12-11	6914	45	7.25	15-20	Avg 1429	175	1450	353	1.68	5-1/2°N6W	"		Bit, bit sub, Baker motor, Y-0, X-0, 2° bent-sub, monel DC, 12-8" DC's	4 8 1	Baker Motor
43	12-1/4"	Sec*	H-100	12-12-12	7003	89	7	15-20	Avg 1429	175	1450	353	1.52	5-3/4°N16E	"		Bit, bit sub, Baker motor, X-0, X-0, 1-1/2° bent sub, monel, 12-8" DC's	4 2 1	Baker Motor
44	12-1/4"	Reed	S74J	12-12-13	7184	181	11	55	4490	60	2500	399	4.74	3-1/4°N39E	"		Bit, 6 pt, monel, DC, RWP, 2 DC's, RWP, 17 DC's	4 4 1	
45	12-1/4"	HTC	J-55	11-11-11	7689	505	21.75	75	6122	60	2500	464	4.82	6°N28E	"		Bit, 6 pt, monel, 2 DC's, RWP, 2 DC's, RWP, 18-8" DC's	8 8 1/4	
46	12-1/4"	STC	F-4	11-11-11	7743	54	3	60	4898	65	2700	464	4.82	7°N27E	"		Bit, 6 pt, 3 DC's, RWP, 2 DC's, RWP, X-0	2 2 1	Junk in hole
47	12-1/4"	HTC	J-55	11-11-11	8204	461	23.75	65	5306	55	2700	464	4.82	15°N13E	"		Bit, junk basket, 6 pt, 3 DC's, X-0, RWP, X-0, 2 DC's, 16-8" DC's, 3 pt, 2 DC's	2 2 1/16	Dyna Drill
48	12-1/4"	Sec*	H-100	15-15-15	8228	24	2.25	20	1633	240	1000	413	1.00		"				
RR#46	12-1/4"	STC	F-4	10-10-11	8268	40	2.75	65	5306	60	2950	464	6.20	16°N13E	"		Bit, 6 pt, 5 DC, RWP, 2 DC, RWP, 19 DC's, 3 pt, 2 DC's	8 8 1/4	
49	12-1/4"	Sec*	H-100	22-22-22	8326	58	4	30	2449	Turbo	3100	464			"		Bit shocksub, turbodrill, X-0, 1-1/2° bent sub, X-0, 12-8" DC's, X-0	2 2 1	Turbo Drill
RR#48	12-1/4"	Sec	H-100	18-13-13	8326	0									"		Bit, 6 pt, monel, DC, 3 pt, 11-8" DC's		Ream Turbo drilled hole
50	12-1/4"	Sec	H-100	18-13-13	8328	2	3	10-25	Avg 1429	Turbo	3100	464	6.02		"		Bit, shocksub, turbo, X-0, 1-1/2° bent sub, X-0, 12-8" DC's	2 2 1	Turbo Drill
51	12-1/4"	Sec*	H-100	22-22-22	8414	86	2-1/2	28	2286	Turbo	1400	371	0.16	16°N17E	"		" " " " " "	8 8 1"	Turbo Drill
RR#50	12-1/4"	Sec	H-100	11-11-11	8414	0									"				
52	12-1/4"	STC*	Q9JL	20-20-20	8545	131	3	10-30	Avg 1633	Turbo	1500	390	0.18	13-3/4°N37E	"		Bit, shock sub, turbo, X-0, 1-1/2° bent sub, X-0, monel, 12-8" DC	8 8 1/2"	ream Turbo drilled hole
53	12-1/4"	Reed	S83J	11-11-11	8575	30	1-1/2	60	4898	70	2900	464	4.82	11-1/4°N29E	"		Bit, 3 pt, monel, DC, 3 pt, 4 DC's, IBS, 17 DC's	2 2 1	Turbodrill run
54	12-1/4"	Sec*	H-100	22-22-22	8575	0	2-1/2	5-40	Avg 1837	Turbo	2100	483			"		Bit, shocksub, turbo, X-0, 1-1/2° bent sub, X-0, monel, 12-8" DC's	2 2 1	Ream Turbodrilled hole
RR#53	12-1/4"	Reed	S83J	11-11-11	8575	0	5	10-30	Avg 1633	55-100	2600	464	4.82		"		Bit, 6 pt, 6 pt, monel, DC, IBS, 21-8" DC's	8 8 1/2	Ream Turbodrilled hole
RR#54	12-1/4"	Sec	H-100	11-11-11	8575	0	3-1/2	40-60	Avg 4082	80	2600	464	4.82		"		" " " " " "	2 2 1	Turbodrill run
55	12-1/4"	STC*	Q9J2	22-22-22	8667	92	3	10-30	Avg 1633	Turbo	1800	413			"		Bit, shocksub, turbodrill, X-0, 2° bent sub, X-0, monel, 8 DC's	8 8 1/2	Ream Turbodrilled hole
RR#54	12-1/4"	Sec*	H-100	11-11-11	8667	0	3	10	816	75	2000	464	4.82		"		Bit, 6 pt, 6 pt, monel, 2 DC's, IBS, 20-8" DC's	2 2 1/8	Ream tight hole
55	12-1/4"	STC	F-5	11-11-11	8975	308	23.75	75	6122	45	2500	464	4.82		"		Bit, 6 pt, 6 pt, monel, DC, IBS, 10-8" DC's	6 6 1	Turbodrill run
RR#54	12-1/4"	Sec	H-100	11-11-11	8975	0									"		" " " " " "		Ream Turbodrilled hole
56	12-1/4"	STC*	Q9JL	22-22-22	9035	60	2.75	25-30	Avg 2245	Turbo	1700	413	0.22		"		Bit, shocksub, turbodrill, 2° bent sub, monel, 8-8" DC's	4 6 1/2	Turbodrill run, Turbodrill would not turn
RR#54	12-1/4"	Sec	H-100	13-13-13	9035	0									"		Bit, 6 pt, 3 pt, 3 pt, monel, 1-8" DC, IBS, 6-8" DC's		
57	12-1/4"	STC*	Q9JL	22-22-22	9035	0									"				
58	12-1/4"	Sec	H-100	11-11-11	9040	5	1.5	20	1633	50	2400	418	3.56	14-3/4°N29E	"		Bit, 6 pt, 3 pt, 3 pt, monel, 1-8" DC, IBS, 6-8" DC's	2 2 1	Turbodrill run
RR#57	12-1/4"	STC*	Q9JL	22-22-22	9082	42	2	20	1633	Turbo	1456	413	2.15	15°N34E	"		Bit, shocksub, turbodrill, X-0, 1-1/2° bent sub, Y-0, monel, 8-8" DC's		ream Turbodrilled hole
RR#58	12-1/4"	Sec	H-100	11-11-11	9082	0									"		Bit, 6 pt, 6 pt, monel, DC, 3 pt, 10-8" DC		Turbodrill run
59	12-1/4"	STC*	Q9JL	20-20-20	9188	106	3	20-30	Avg 2041	Turbo	1800	464	0.44		"		Bit, shocksub, turbodrill, Y-0, 2° bent sub, X-0, monel, 8-8" DC's	8 8 1/4	ream Turbodrilled hole
RR#54	12-1/4"	Sec	H-100	11-11-11	9188	0									"		Bit, 6 pt, monel, 3 pt, 7-8" DC's	8 8 1/4	Ream Turbodrilled hole
RR#58	12-1/4"	Sec	H-100	11-11-11	9188	0									"		Bit, 6 pt, 6 pt, monel, IBS, 8-8" DC's		Turbodrill run
60	12-1/4"	STC*	Q9JL	22-22-22	9311	123	3	10-38	Avg 1959	Turbo	2000	464	0.30	13-1/2°N40E	"		Bit, shocksub, turbodrill, X-0, 1-1/2° bent sub, X-0, 8-8" DC's	8 8 1/2	ream Turbodrilled hole
61	12-1/4"	STC	F-9	11-11-11	9311	0									"		Bit, 6 pt, 6 pt, monel, 3 pt, 3-8" DC's, IBS, 5-8" DC's	2 2 1/16	Turbodrill run
62	12-1/4"	STC*	Q9JL	22-22-22	9363	52	2-1/2	30	2449	Turbo	2200	464	0.30	13-1/4°N12E	"		Bit, shocksub, turbodrill, X-0, 1-1/2° bent sub, X-0, 8-8" DC's	8 8 1/16	Ream Turbodrilled hole
RR#61	12-1/4"	STC	F-9	11-11-11	9363	0									"		Bit, 6 pt, 6 pt, monel, 5 DC's, 3 pt, 3 DC's	4 4 1	Turbine would not turn
63	12-1/4"	STC	Q9JL	20-20-20	9467	104									"		Bit, shocksub, turbodrill, X-0, 2° bent sub, X-0, 8-8" DC's		
RR#61	12-1/4"	STC	F-9	11-11-11	9467	0									"		Bit, 6 pt, 6 pt, monel, IBS, 8-8" DC's	4 4 1/16	ream Turbodrilled hole
64	12-1/4"	Sec*	H-100	20-20-20	9513	46	2	30	2449	Turbo	2000	464	0.44	12-1/4°N51E	"		Bit, shocksub, turbodrill, X-0, 2° bent sub, X-0, 8-8" DC's	8 8 1/16	Turbo run
RR#61	12-1/4"	STC	F-9	11-11-11	9513	0									"		Bit, 6 pt, 6 pt, monel, IBS, 8-8" DC's	4 4 1/4	Ream Turbodrilled hole

APPENDIX C (cont)

SUMMARY OF EE-2 BIT RUNS

Bit #	Size	Make	Type	Jets	Depth Out	Footage	Hours	Bit wt 1000#	#/dia Inch	RPM	Pump Pressure	Pump Rate GPM	HHP/in. ²	Deviation & Direction	MW	PV	BHA	Condition T B G	Remarks
65	12-1/4"	Sec*	H-100	20-20-20	9531	18	1/2	30	2449	Turbo	2000	464	0.44		Water		Bit, shocksub, turbodrill, X-0, 2° bent sub, X-0, 8-8" DC's	8 8 1	Turbodrill run
66	12-1/4"	Reed	S74J	11-11-11	9616	25	8	75	6122	55	2800	464	4.82	11°N51E	"		Bit, 6 pt, 6 pt, monel, 2 DC's, 3 pt, 22 DC's, 3 pt, 3 DC's	4 8 1	Assembly run to build angle
67	12-1/4"	STC	F-9	11-11-11	9642	86	4.5	85	6939	55	2600	464	4.82	12°N50E	"		Bit, 6 pt, monel, 21 DC's	8 4 1/4	" " " " "
68	12-1/4"	Reed	S83J	11-11-11	9718	76	8.5	60	4898	40	2400	464	4.82	11-3/4°N45E	"		Bit, 3 pt, monel, DC, 3 pt, 16 DC's	4 4 1/16	" " " " "
69	12-1/4"	HTC	J77	11-11-11	9766	48	4	70	5714	40	2400			12°N42E	"			2 4 1	
70	12-1/4"	Sec*	H-100	20-20-20	9776	10	2.5	30	2449	Turbo		464	0.44		"		Bit, turbodrill, 2° bent sub, X-0, monel, 8-8" DC's	4 4 1/8	Turbodrill
RR#69	12-1/4"	HTC	J-77	11-11-11	9787	11	1.5	70	5714	40	2400	464	4.82		"		Bit, junk sub, 6 pt, 3 pt, monel, 3 pt, 17-8" DC's	4 4 1/8	Run to ream Turbodrilled hole
71	12-1/4"	Reed*	S74J	11-12-13	9838	51	10.5	10	816	Baker Mtr		1600	371	1.76	"		Bit, X-0, Baker motor, float sub, 2° bent sub, X-0, monel, 8-8" DC's	3 3 1/16	Baker motor run
RR#68	12-1/4"	Reed	S83J	11-11-11	9840	2	.5	40	3263	65	1700	394	2.95	12-1/4°N50E	"		Bit, 6 pt, X-0, IBS, X-0, monel, 3 pt, DC, 3 pt, 18 DC's	4 4 1/2	Ream directional hole
72	12-1/4"	Reed*	S74J	12-12-13	9850	10	6.5	4	327	Baker Mtr		1600	371	1.56	"		Bit, X-0, Baker motor, float-sub, 2° bent-sub, X-0, monel, 8-8" DC's	1 1 1	Baker motor run
73	12-1/4"	STC*	Q9JL	20-20-20	9912	62	3.5	15	1224	Turbo	1400	325	0.15		"		Bit, turbodrill, 2° bent sub, X-0, monel, 8-8" DC's	4 6 1/16	Turbodrill run
RR#68	12-1/4"	Reed	S83J	12-12-12	9917	5	1	70	5714	45	1500	357	1.58	3°N59E	"		Bit, 6 pt, monel, 3 pt, 8" DC, 3 pt, 15-8" DC's	4 7 1/16	Ream Turbodrilled hole
74	12-1/4"	STC*	Q9JL	20-20-20	10,035	118	5.5	12	980	Turbo	1500	357	0.20		"		Bit, turbodrill, X-0, 2° bent sub, X-0, shocksub, monel, 8-8" DC's	6 6 1/8	Turbodrill run
RR#72	12-1/4"	Reed	S74J	12-12-13	10,035	0									"		Bit, 6 pt, 3 pt, monel, 3 pt, DC, 3 pt, 15 DC's		Lost returns while reaming - Hole in csg. @ 1790'
75	12-1/4"	STC	DTJ	11-11-11	Drill Cmt	8.5	10	816	.50		2400	464	4.82		"		Bit, 9-8" DC's	2 2 1	Drill cement 1480' - 1865'
76	12-1/4"	HTC	J-55	11-11-11	10,067	32	2	70	5714	50-55	2400	464	4.82	15-1/2°N74E	"		Bit, 6 pt, monel, 19 DC's, 3 pt, 2-8" DC's	2 4 1	Drill string pulled in two hole making a connection
77	12-1/4"	STC	SJ5	14-14-14	10,295	228	19.5	65	5306	55	1600	441	1.59	17-1/4°N78E	"		Bit, 3 pt, float sub, monel, DC, X-0, 6 pt, X-0, DC, 3 pt, 9 DC's, X-0 27 JLS HWDP	6 6 1/8	Building assembly
78	12-1/4"	STC	F-5	14-14-14	10,433	138	11	60	4898	55	1600	464	1.84	17°N77E	"		Bit, 3 pt, float sub, monel, DC, 3 pt, DC, 3 pt, 11-8" DC's, 27 JLS HWDP	4 2 1	Pull, Assembly losing angle
79	12-1/4"	STC	Q9JL	20-20-20	10,552	89	4.5	15	1224	Turbo	1500	348	0.19	21°N70E	"		Bit, turbodrill, X-0, 1-1/2° bent sub, X-0, monel, 2 DC's, X-0, 25 JLS HWDP	8 8 1/2	Turbodrill run
RR#78	12-1/4"	STC	F-5	14-14-14	10,522	0									"		Bit, 6 pt, 3 pt, 8" DC, 3 pt, 2-8" DC's, X-0, 25 TLS HWDP		ream turbodrilled hole
80	12-1/4"	Reed	FP63	11-11-11	10,691	169	8.5	60	4898	55	2600	464	4.82	22-1/2°N72E	"		Bit, 3 pt, float sub, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, 3 pt, 11-8" DC, X-0, 12 TLS HWDP, jars,	4 4 1/4	Pulled due to slowing of build rate
81	12-1/4"	HTC	J-55	11-11-11	10,733	42	4	55	4490	55	2600	464	4.82		"		Bit, 3 pt, float sub, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, 3 pt, 11-8" DC, X-0, 12 TLS HWDP, jars,		Survey line broke - POOH
RR#81	12-1/4"	HTC	J-55	11-11-11	10,733	0									"		Bit, 6 pt, 3 pt, 1-8" DC, 3 pt, 2-8" DC's, 12 TLS HWDP, jars, 9 pts, HWDP	4 4 1/8	Ream tight hole
82	12-1/4"	STC	F-5	11-11-11	10,876	143	11	53	4327	55	2300	418	3.56	24°N67E	"		Bit, 3 pt, float, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, X-0, 3 pt, 10-8" DC's, X-0, 12 TLS HWDP, X-0, jars, X-0, 4	5 5 1/8	Pulled due to slowing of build rate
83	12-1/4"	HTC	J-55	14-14-14	11,000	124	9	60	4898	55	2200	418	1.34	26°N64E	"		Bit, 3 pt, float, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, X-0, 3 pt, 10-8" DC's, X-0, 12 TLS HWDP, X-0, jars, X-0, 4-	4 4 1/4	" " " " "
84	12-1/4"	Sec	M89TF	11-11-11	11,097	97	10.5	60	4898	55	2200	418	3.56	27-1/2°N61E	"		Bit, 3 pt, float, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, X-0, 3 pt, 10-8" DC's, X-0, 12 TLS HWDP, X-0, 4	8 8 1/4	Possible junk in hole
RR#83	12-1/4"	HTC	J-55	11-11-11	11,097	0									"		Bit, junk basket, 6 pt, X-0, 8" DC, 3 pt, 3 DC's, 9 TLS HWDP, X-0, jars X-0, 12 JTS HWDP	4 4 1/4	Reamed & washed on junk
85	12-1/4"	STC	F-5	11-11-11	11,224	127	13.5	60	4898	55	2200	418	3.56	28-1/2°N62E	"		Bit, 3 pt, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, X-0 3 pt, 11-8" DC, X-0, 8 JTS HWDP, X-0, jars, X-0, 13 JTS, HWDP	4 4 1/16	Pulled due to slowing of build rate
86	12-1/4"	HTC	J55	11-11-11	11,289	65	6.5	65	5306	55	2200	418	3.56		"		Bit, 3 pt, X-0, 6-3/4" monel, 6-3/4" DC, 6-3/4" SDC, X-0, 3 pt, 11-8" DC, X-0, 8 JTS HWDP, X-0, jars, X-0, 13 JTS HWDP	8 8 1"	Possible junk in hole
RR#85	12-1/4"	STC	F-5	11-11-11	11,289	0									"		Bit, junk basket, 6 pt, 1-8" DC, 3 pt, 3-8" DC's, X-0, 8 JTS HWDP, X-0, jars, X-0, 13 JTS HWDP		Ream & wash on junk
87	12-1/4"	STC	F-9	11-11-11	11,306	17	1.5	60	4898	55	2200	418	3.56	29°N59E	"		Bit, 3 pt, X-0, 6-3/4" monel, 6-3/4" SDC, 6-3/4" DC, X-0, 3 pt, 11-8" DC's, X-0, 8 JTS HWDP, X-0, jars, X-0, 13JLS HWDP	8 8 1/16	
88	12-1/4"	Sec	H-100	14-14-14	11,308	2	0.5	60	4898	55	2200	557	3.20		"		" "		

SUMMARY OF EE-2 BIT RUNS

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APPENDIX C (cont)
SUMMARY OF EE-2 BIT RUNS

Bit #	Size	Make	Type	Jets	Depth Out	Footage	Hours	Bit wt 1000#	#/dia Inch	RPM	Pump Pressure	Pump Rate GPM	HHP/in. ²	Deviation & Direction	MW	PV	BHA	Condition			Remarks
																		T	B	G	
136	8-3/4"	Sec	H-100	12-12-15	13,950	13	6	5-15	Avg 1143	50	1500	340	2.18		Water		Bit, junk basket, X-0, 1 6-3/4" DC, 18 JTS HWDP, jars, 12 JTS HWDP				Ream core hole and drill on a little junk
137	8-3/4"	STC	7GA	11-11-12	13,956	6	0.5	40	4571	50	400	297	-		"		Bit, junk basket, 6 pt, 5 DC, 3 pt, monel, 3 pt, 6 6-3/4" DC's, jars, 30 JTS HWDP	4	2	1	Lost 800# pressure (bit design)
138	8-3/4"	STC	7GA	11-11-12	14,189	233	23	32	3657	50	1600	405	-	34-1/2°N74E	"			4	3	1/16	Pulled due to torque
RR#137	8-3/4"	STC	7GA	11-11-12	14,501	312	33.5	40	4571	55	1600	405	-		"		Bit, 6 pt, 5 DC, 3 pt, monel, 3 pt, 6 6-3/4" DC's, jars, 30 JTS HWDP	5	5	1/16	Twisted off in the collars
139	7-7/8"	STC	Core Bt	-	14,504	3	1	10	1270	40	300	243	-		"		Bit, core bbl, X-0, monel, 15 JTS HWDP, jars, 15 JTS HWDP	Dull			Monel plugged off around orientation tool
140	8-3/4"	STC	7GA	11-11-11	14,962	462	42	35-40	Avg 4286	55	1600	405	-	35°N79E	"		Bit, 6 pt, 5 DC, 3 pt, monel, 3 pt, 7 6-3/4" DC's, jars, 30 JTS HWDP	7	7	1/4	
141	7-7/8"	STC	Core Bt	-	14,966	4	1.5	8	901	40	300	200	-		"		Core bit, core bbl, 1 6-3/4" DC, 15 JTS HWDP, jars, 15 JTS HWDP	Dull			Cored 4' recovered 2-1/2'
142	8-3/4"	STC	7GA	12-12-11	15,273	307	22.5	35-40	Avg 4286	55	1500	405	-		"		Bit, 6 pt, SDC, 3 pt, monel, 3 pt, 7 6-3/4" DC's, jars, 30 JTS HWDP				Lost cone in hole
143	8-3/4"	STC	7GA	12-12-11	15,273	0	-	-	-	-	-	-	-		"		Bit, X-0, junk basket, 2-monel collars, 15 JTS HWDP, jars, 15 JTS HWDP				Run on BHA for multi-shot survey only
144	8-3/4"	STC*	7GA	15-15-15	15,282	8	3	7-10	-	250-400	2400	351	-		"		Bit, X-0, turbo drill, X-0, monel, 15 JTS HWDP, jars, 15 JTS, HWDP				Run on Maurer Turbo-Drill test
144RR	8-3/4"	STC*	7GA	22-22-22	15,289	7	2.5	7-10	-	400	2400	351	-		"		Bit, X-0, turbo drill, X-0, monel, 3 drill collars, 15 HWDP, jars, 15 HWDP				Run on Maurer Turbo-Drill test

APPENDIX D

CASING COLLAPSE HISTORY

<u>Date</u>	
12/21/79	While cutting Core No. 5, it was noted that only partial returns were making it to the surface. A temperature log was run indicating that the loss zone was at 2375-ft KB and 400 sacks of cement were ordered out.
12/22/79	The drill pipe was being tripped in open ended when an obstruction was encountered at 1772-ft KB (SLM). An impression block was run revealing that the 13-3/8-in. casing had collapsed.
12/23/79	The casing was swedged from 1776 ft to approximately 1786 ft. A TV camera was run in the well showing the collapsed casing. A 7-in. casing roller was run into the well.
12/24/79	The casing was rolled out from 1776 ft to 1782 ft. This run was followed by a 12-1/4-in. casing roller, and the casing was rolled from 1762 ft to 1771 ft. Due to the slow penetration rate, a 7-in. casing roller was run to 1772-ft KB.
12/25/79	The 7-in. casing roller was unable to make footage; therefore, it was pulled. A 9-5/8-in. casing roller also failed to make any footage at 1772-ft KB. A TV camera was run in the hole; however, murky water prevented aquisition of any useful data. A 4-in. casing swedge was run and the casing was swedged from 1772 ft to 1777 ft.
12/26/79	An 8-in. casing swedge was run, and the casing was swedged from 1771 ft to 1789 ft. A 9-5/8-in. casing roller was run, and the casing was rolled from 1771 ft to 1789 ft. When the roller wore out, a 10-3/4-in. casing roller was run in the well.
12/27/79	The casing was rolled from 1769 ft to 1791 ft with the 10-3/4-in. casing roller. There were no restrictions in the casing from 1791 ft to 1814 ft. The 10-3/4-in. roller was unable to make any footage at 1814 ft. Upon pulling the 10-3/4-in. casing roller, it was discovered that 3 rollers and 1 nose cone had been left in the hole. A magnet was run to recover the fish, but the trip was unsuccessful. The magnet would not go past 1795-ft KB. A 12-1/4-in. swedge was run, and the casing was swedged from 1766 ft to 1783 ft.

APPENDIX D (CONT)

<u>Date</u>							
12/28/79	A 12-1/4-in. casing roller was run, and the casing rolled from 1766 ft to 1777 ft when high torque caused the operation to be abandoned. A TV camera was run to 1763 ft showing a split in the casing below the 13-3/8-in. FO stage collar.						
12/29/79	<p>An 8-in. and 12-1/4-in. swedge were run from 1789 ft to 1800 ft. The swedges would not go past 1800 ft. An impression block was run and showed a crescent-shaped object. A magnet was run, but it did not recover anything. A TV camera was run and showed the following:</p> <table border="0"><tr><td>1762 ft to 1783 ft</td><td>3 splits, 1/2-in to 3-in. wide</td></tr><tr><td>1783 ft to 1792 ft</td><td>casing appears to be good</td></tr><tr><td>1792 ft</td><td>a piece of casing has folded out and is blocking the wellbore</td></tr></table> <p>A 8-in. flat-bottom mill was run in the hole, and the casing was milled from 1792 ft to 1796 ft.</p>	1762 ft to 1783 ft	3 splits, 1/2-in to 3-in. wide	1783 ft to 1792 ft	casing appears to be good	1792 ft	a piece of casing has folded out and is blocking the wellbore
1762 ft to 1783 ft	3 splits, 1/2-in to 3-in. wide						
1783 ft to 1792 ft	casing appears to be good						
1792 ft	a piece of casing has folded out and is blocking the wellbore						
12/30/79	A 12-1/4-in. tapered mill and stabilizer bottom-hole assembly was run. The casing was milled from 1786 ft to 1792 ft. The mill was pushed to 1812 ft. The mill was tripped out of the hole to run a TV camera, but the fluid level was too high. A 9-7/8-in. tapered mill was run from 1791 ft to 1795 ft with moderate torque.						
12/31/79	A 12-1/4-in. tapered mill was run to 1792 ft, but it would not rotate. A 9-7/8-in. tapered mill and 12-1/4-in. swedge were run from 1792 ft to 1796 ft. A 11-1/2-in. magnet was run to try to pick up the 10-3/4-in. casing rollers. While tripping in the hole, a 22-ft mistake was found in the pipe strap. This would cause the depths reported since 12/27/79 to be 22 ft shallower. The magnet was unsuccessful in picking up anything. Another attempt was made to run the TV camera, but the fluid level was too high. A 9-7/8-in. mill and 12-1/4-in. swedge were run from 1792 ft to 1796 ft. The 9-7/8-in. mill was replaced with a 8-in. swedge to allow the swedge to be driven deeper.						
1/1/80	The casing was swedged from 1796 ft to 1798 ft but would not go any deeper. A 10-5/8-in. impression block was run to 1790 ft and showed collapsed casing. A 7-3/4-in. impression block was run and showed collapsed casing and fill on bottom. A 9-7/8-in. tapered mill was run from 1793 ft to 1798 ft to clean out fill.						

APPENDIX D (CONT)

Date

- 1/2/80 A 8-in. swedge was run from 1798 ft to 1804 ft and 2 in. of the nose was left in the hole. A 12-1/4-in. swedge was run to 1804 ft but would not go deeper. The bottom of the 12-1/4-in. swedge was flared. It was suspected that the swedges were being stopped by junk. A 7-3/4-in. impression block was run and indicated possible junk on bottom. A 8-5/8-in. junk mill was run from 1802 ft to 1805 ft. Then a 12-1/4-in. tapered mill was run from 1793 ft to 1801 ft.
- 1/3/80 A 8-in. magnet and two junk baskets were run to 1804 ft recovering only two small pieces of casing. A 6-1/4-in. diamond point and 12-1/4-in. swedge were run from 1804 ft to 1810 ft where it was stopped when not enough water was available to continue circulating. After tripping, the diamond point and 12-1/4-in. swedge were run from 1805 ft to 1810 ft.
- 1/4/80 A 9-7/8-in. mill was run from 1804 ft to 1815 ft. Then an 11-in. magnet and junk sub were run with no recovery. A 5-1/2-in. and 12-1/4-in. swedge were run from 1800 ft to 1814 ft. The swedges got stuck but were jarred loose. A 8-in. swedge was run in the hole to 1813 ft but could not get any deeper.
- 1/5/80 A 9-7/8-in. mill and 12-1/4-in. swedge were run in the hole to 1816 ft, but they made no progress. It appeared that the 9-7/8-in. tapered mill had been turning inside the 10-3/4-in. casing roller. A 11-in. magnet was run to 1816 ft recovering a small piece of casing. A TV camera was run in the hole. It showed that the casing had severely worn since the camera run of 12/23/79. The TV camera was hanging up on a piece of casing at 1772 ft and would go no deeper. At that time it was decided to reinforce the casing by putting cement behind it. Bridging material was placed above the 10-3/4-in. casing rollers at 1814-ft KB.
- 1/6/80 The bridging material was pushed to 1809 ft, and 9 sacks of sand were spotted on top. The sand was tagged at 1800-ft KB. The drill pipe was run in the hole open ended to 1797 ft and 100 sacks of Class B cement with 2% CaCl₂ were spotted. A 12-1/4-in. mill and stabilized bottom-hole assembly were run to 1783 ft but did not tag any cement. The drill pipe was run in the hole pushing more bridging material.

APPENDIX D (CONT)

<u>Date</u>	
1/7/80	The bridging material was pushed to 1809-ft KB and 50 barrels of mud with lost circulation material were spotted on top. Six sacks of sand were dumped on top of the bridge and tapped at 1804-ft KB. With the open ended drill pipe at 1797 ft, 100 sacks of Thixset cement containing 2% CaCl_2 were spotted in the casing. After waiting 6 hours, the cement was tagged at 1802-ft KB. The casing was cemented with 100 sacks of Class B cement containing 2% CaCl_2 with the drill pipe open ended at 1796-ft KB. After waiting 6 hours, the cement was tagged at 1801-ft KB.
1/8/80	With the drill pipe open ended at 1796-ft KB, 50 bbls of mud with 30 lbs/bbl of lost circulation material were pumped followed by 40 bbls of water. Two hundred sacks of Thixset cement containing 3% CaCl_2 were pumped. After 3 hours, the cement was tagged at 1799 ft. All but one stand of drill pipe was pulled out of the hole, and the casing was cemented with 100 sacks of Thixset cement containing 3% CaCl_2 . One and one-half hours later, the casing was cemented again with 100 sacks of Thixset cement containing CaCl_2 .
1/9/80	The cement was tagged at 1797-ft KB. With 1 stand of drill pipe in the hole, the casing was cemented with 100 sacks of Halco light cement containing 3% CaCl_2 , 12.5 lbs/sack Gilsonite, and 1/4 lb/sack flocele. Two and one-half hours later the casing was again cemented with 100 sacks of Halco light cement combination 3% CaCl_2 , 12.5 lbs/sack Gilsonite, and 1/4 lb/sack flocele. After 2 hours, the cement was tagged at 1585-ft KB. A bit and stabilized bottom-hole assembly were run and soft cement was drilled from 1765-ft KB to 1750-ft KB.
1/10/80	A mill and stabilized bottom-hole assembly was run. The rig broke down and required repair at this time.
1/11/80	Cement was milled from 1744-ft KB to 1774-ft KB where returns were lost. The drill pipe was run in the hole open ended to 1780-ft KB, and a 50-bbl mud pill with lost circulation material were pumped and then followed by 200 sacks of Thixotropic cement with 12.5 lbs/sack Gilsonite and 1/4 lb/sack flocele.
1/12/80	After waiting on cement 8-1/2 hours, the cement was tagged at 1759-ft KB. A mill and stabilized bottom-hole assembly were run, and the cement was milled from 1754-ft KB to 1767-ft KB where returns were lost.

APPENDIX D (CONT)

Date

1/13/80

The drill pipe was run in the hole open ended to 1765-ft KB. The casing was cemented with 200 sacks of Thixotropic cement containing 12.5 lbs/sack Gilsonite, 1/2 lb/sack flocele, and 3% CaCl_2 . A 12-1/4-in. mill and stabilized bottom-hole assembly were run, and cement was drilled from 1707-ft KB to approximately 1780-ft KB. Cement and casing were milled from 1780-ft KB to 1783-ft KB.

APPENDIX E

PHOTOGRAPHS TAKEN THROUGHOUT DRILLING EE-2

Ground breaking for EE-2.

Zia Company (Caldwell Rig) drilling the conductor pipe hole for EE-2.

Placing the 100-ft long, 28-in.-diam conductor pipe.

Zia Company drilling the rat hole and mouse hole for EE-2.

GSM's Rich Carden mixes barite in mud pit for pumpdown prior to cementing the 9-5/8-in. injection casing in EE-2.

Halliburton cementing trucks at the EE-2 injection casing cementing operation on April 31, 1980.

Wireline packoff for directional instrumentation.

Three-pronged wireline fishing tool used to snag 8000-ft wireline fish.

Upper portion of wireline fish jammed in drill pipe.

GSM's Ralph Burnett inspects the retrieved wireline fish.

Example of a washout found in the drill pipe.

Lay-down machine for drill pipe inspection conducted on December 16, 1979.

Bent drill pipe from parted drill-string that broke at 4549 ft.

Pipe straightening operation.

Cablehead for steering tool.

Steering tool used at cooler intervals.

Joe Kurtenbach, of Los Alamos, refurbishing the Maurer turbodrill.

Steering tool used for directional drilling.

HOMCO overshot tool for fishing drill pipe.

Portion of 13-3/8-in. collapsed casing that corkscrewed up into the drill-string through a mill.

New tungsten carbide chip covered casing mill.

Shock sub and bit.

Typical BHA--bit, junk basket and near bit reamer.

Roughnecks installing jets into a 12-3/4-in. bit.

Close-up of EE-2 shock subs, roller and RWP stabilizers.

Junk basket being made-up on BHA.

Severe wear on integral blade stabilizer.

Examples of uneven wear
on roller reamers,
during contact with
biotite granodiorite
at 9000 ft.

Examples of wear on
reamer rollers from
between 7000 and
10 000 ft.

Texas reamer with new
rollers.

New and used bits for EE-2.

EE-2 cuttings, note difference in size.

APPENDIX F

N Baroid

GRAPHIC RECORD

APPENDIX G

INDEX OF DAILY REPORTS COVERING ENTIRE DRILLING PERIOD OF EE-2 AT THE UNIVERSITY OF CALIFORNIA-FENTON HILL GEOTHERMAL SITE (March 25, 1979 through May 16, 1980)

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks	
March 25-April 2, 1979, Rig Mobilization at Fenton Hill						
<u>1979</u> Apr.	3	Spud	0	0	-	Picked up 1st BHA for spud
	4	1	212	212	26	Drill
	5	2	420	208	26	Drill
	6	3	565	145	26	Drill
	7	4	740	175	26	Drill--Trip for bit change -- survey
	8	5	914	175	26	Drill--survey
	9	6	938	24	26	Drill--survey--trip for bit change
	10	7	938	0	26	Trip for stabilizer--ream
	11	8	1052	114	26	Drill--survey--first lost circulation
	12	9	1174	122	26	Drill--survey
	13	10	1303	129	26	Drill--trip for bit change--survey
	14	11	1540	237	26	Drill--survey
	15	12	1705	165	26	Drill--survey
	16	13	1785	80	26	Drill--trip for bit change--complete 26" drill
	17	14	1785	0	26	Prepare to run 20" casing--survey

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
18	15	1785	0	26	Run 20" casing--torque-up problems
19	16	1785	0	26	Run 20" casing
20	17	1785	0	26	Run 20" casing to 1782.7'--cement
21	18	1785	0	26	Place landing base--nipple up return line for 17-1/2" bit run
22	19	1909	124	17-1/2	Drill--2nd lost circulation--change 17-3/4" to 17-1/2"
23	20	2043	134	17-1/2	Drill--trip for bit change--survey
24	21	2202	159	17-1/2	Drill--survey
25	22	2323	121	17-1/2	Drill--trip for bit change--survey--reaming
26	23	2463	140	17-1/2	Drill--trip to remove stabilizers--3rd lost circulation
27	24	2557	94	17-1/2	Drill with no returns--trip for bit change--survey--ream
28	25	2593	36	17-1/2	Drill--trip for bit change--first indication of cavern--change 2953' to 2593'
29	26	2593	0	17-1/2	Sloughing hole--cement at cavern, 1st plug
30	27	2593	0	17-1/2	Set 2nd cement plug at 2450'
1979 May	1	2593	0	17-1/2	Drill cement
	2	2593	0	17-1/2	Run 13-3/8" casing
	3	2593	0	17-1/2	Run 13-3/8" casing--cement 1st stage

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
4	31	2593	0	17-1/2	Re-cement 1st stage
5	32	2593	0	17-1/2	Cement 2nd stage 13-3/8" casing
6	33	2593	0	17-1/2	Wait for cement cure
7	34	2593	0	17-1/4	Drill cement and retainer
8	35	2610	17	12-1/4	Drill--lost bit cones
9	36	2610	0	12-1/4	Attempt to recover cones--4th lost circulation--temperature log
10	37	2610	0	12-1/4	Run Magnet to retrieve cones--caliper log
11	38	2610	0	12-1/4	Roll casing--log
12	39	2610	0	12-1/4	Log
13	40	2610	0	12-1/4	Log
14	41	2619	0	12-1/4	Next cementing plan--determine depth of 12-1/4" hole
15	42	2619	0	12-1/4	Log-prepare to cement
16	43	2619	0	12-1/4	Cement loss zone
17	44	2619	0	12-1/4	Drill cement
18	45	2619	0	12-1/4	Drill cement
19	46	2619	0	12-1/4	Drill cement--log
20	47	2619	0	12-1/4	Drill cement--5th lost circulation
21	48	2619	0	12-1/4	Drill through casing at 2412'
22	49	2619	0	12-1/4	Drill sidetrack in granite to 2426'
23	50	2619	0	12-1/4	6th lost circulation-- drill in granite to 2514'

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
24	51	2619	0	12-1/4	Temperature log--cement plug
25	52	2619	0	12-1/4	Drill cement plug--drill granite to 2559'
26	53	2619	0	12-1/4	Drill granite to 2602'--7th lost circulation--cement plug
27	54	2619	0	12-1/4	Drill cement
28	55	2641	22	12-1/4	Drill cement, granite--8th lost circulation
29	56	2641	0	12-1/4	Plan massive cementing
30	57	2641	0	12-1/4	Massive cementing
31	58	2641	0	12-1/4	Drill cement
<u>1979</u> <u>June</u>					
1	59	2785	144	12-1/4	Drill granite
2	60	2943	158	12-1/4	Drill granite
3	61	3042	99	12-1/4	Drill granite
4	62	3200	158	12-1/4	Drill granite
5	63	3265	65	12-1/4	Drill granite
6	64	3330	65	12-1/4	Drill granite
7	65	3450	120	12-1/4	Drill granite
8	66	3584	134	12-1/4	Drill granite
9	67	3631	47	12-1/4	Drill granite
10	68	3780	149	12-1/4	Drill granite
11	69	3893	113	12-1/4	Drill granite
12	70	3961	68	12-1/4	Drill granite
13	71	4020	59	12-1/4	Drill granite
14	72	4138	118	12-1/4	Drill granite

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
15	73	4233	95	12-1/4	Drill granite
16	74	4333	100	12-1/4	Drill granite
17	75	4340	7	12-1/4	Parted drill pipe in hole
18	76	4340	0	12-1/4	Inspection of drill pipe
19	77	4340	0	12-1/4	Dropped stabilizer blade in hole
20	78	4340	0	12-1/4	Mill
21	79	4340	0	12-1/4	Mill
22	80	4362	22	12-1/4	9th lost circulation
23	81	4362	0	12-1/4	Log and cement
24	82	4362	0	12-1/4	Wait on cement cure
25	83	4428	66	12-1/4	Drill cement and granite
26	84	4642	214	12-1/4	Drill granite
27	85	4848	206	12-1/4	Drill granite
28	86	4912	64	12-1/4	Maurer turbodrill test
29	87	5012	100	12-1/4	Ream and drill granite
30	88	5012	0	12-1/4	Parted cross-over in hole
<u>1979</u> July 1	89	5094	82	12-1/4	Retrieve cross-over and drill granite
2	90	5260	166	12-1/4	Washout on drill collar
3	91	5464	204	12-1/4	Drill granite
4	92	5600	136	12-1/4	Drill granite
5	93	5879	279	12-1/4	Drill granite--recover wireline
6	94	6166	287	12-1/4	Drill granite
7	95	6492	326	12-1/4	Drill granite

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
8	96	6531	39	12-1/4	Directionally drill--Dyna Drill
9	97	6546	15	12-1/4	Directionally drill--Dyna Drill
10	98	6597	51	12-1/4	Directionally drill--Dyna Drill
11	99	6597	0	12-1/4	Ream hole to gauge
12	100	6613	16	12-1/4	Ream and rotary drill
13	101	6619	6	12-1/4	Rotary drill and directionally drill--Dyna Drill
14	102	6748	129	12-1/4	Ream and run Baker motor
15	103	6818	70	12-1/4	Run Baker motor
16	104	6880	62	12-1/4	Ream, drill and run Baker motor
17	105	6998	118	12-1/4	Run Baker motor
18	106	7146	148	12-1/4	Run Baker motor and drill
19	107	7374	228	12-1/4	Drill--washout
20	108	7689	315	12-1/4	Drill
21	109	7763	74	12-1/4	Drill
22	110	8168	405	12-1/4	Drill
23	111	8226	58	12-1/4	Run Dyna-Drill motor and drill
24	112	8268	42	12-1/4	Drill
25	113	8268	0	12-1/4	Run Maurer turbodrill
26	114	8328	60	12-1/4	Run Maurer turbodrill
27	115	8328	0	12-1/4	Ream
28	116	8418	90	12-1/4	Run Maurer turbodrill
29	117	8545	127	12-1/4	Run and ream Maurer turbodrill

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
30	118	8575	30	12-1/4	Drill
31	119	8575	0	12-1/4	Run Maurer turbodrill
<u>1979</u> Aug. 1	120	8575	0	12-1/4	Ream--Washout
2	121	8637	62	12-1/4	Ream--run Maurer turbodrill
3	122	8667	30	12-1/4	Run Maurer turbodrill and ream
4	123	8667	0	12-1/4	Run Maurer turbodrill
5	124	8675	8	12-1/4	Run Maurer turbodrill run and drill
6	125	8879	204	12-1/4	Drill
7	126	8975	0	12-1/4	Drill
8	127	8975	0	12-1/4	Inspect rig's drill pipe
9	128	8975	0	12-1/4	Ream
10	129	9035	60	12-1/4	Run Maurer turbodrill
11	130	9035	0	12-1/4	Ream
12	131	9035	0	12-1/4	Run Maurer turbodrill--washouts
13	132	9035	0	12-1/4	Ream
14	133	9082	47	12-1/4	Run Maurer turbodrill
15	134	9088	6	12-1/4	Ream
16	135	9188	100	12-1/4	Run Maurer turbodrill
17	136	9188	0	12-1/4	Ream
18	137	9188	0	12-1/4	Ream
19	138	9188	0	12-1/4	Ream--rig power outage
20	139	9248	60	12-1/4	Run Maurer turbodrill
21	140	9311	63	12-1/4	Run Maurer turbodrill and ream

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
22	141	9322	11	12-1/4	Run Maurer turbodrill
23	142	9362	40	12-1/4	Run Maurer turbodrill and ream
24	143	9362	0	12-1/4	Run Maurer turbodrill
25	144	9362	0	12-1/4	Wait on directional control
26	145	9467	104	12-1/4	Run Maurer turbodrill
27	146	9467	0	12-1/4	Ream and run Maurer turbodrill
28	147	9513	46	12-1/4	Ream
29	148	9531	18	12-1/4	Run Maurer turbodrill
30	149	9616	85	12-1/4	Ream and drill
31	150	9642	36	12-1/4	Drill
<u>1979</u>					
Sept 1	151	9734	92	12-1/4	Drill
2	152	9766	32	12-1/4	Drill
3	153	9786	20	12-1/4	Run Maurer turbodrill and drill
4	154	9786	0	12-1/4	Wait on motor
5	155	9786	0	12-1/4	Pick up Baker motor
6	156	9835	49	12-1/4	Run Baker motor
7	157	9840	5	12-1/4	Ream and run Baker motor
8	158	9850	9	12-1/4	Run Baker motor
9	159	9912	62	12-1/4	Run Maurer turbodrill
10	160	9945	33	12-1/4	Ream, drill--run Maurer turbodrill
11	161	10035	90	12-1/4	Run Maurer turbodrill--ream
12	162	10035	0	12-1/4	10th lost circulation while reaming
13	163	10035	0	12-1/4	Cement loss zone

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
14	164	10035	0	12-1/4	Drill cement
15	165	10067	32	12-1/4	Log (temp)--parted drill pipe
16	166	10067	0	12-1/4	Fish for drill pipe
17	167	10067	0	12-1/4	Break out drill pipe
18	168	10067	0	12-1/4	Free point run
19	169	10067	0	12-1/4	Remove 5 drill collars
20	170	10067	0	12-1/4	Fish--break out
21	171	10067	0	12-1/4	Part 8000 ft wireline
22	172	10067	0	12-1/4	Fish for wireline
23	173	10067	0	12-1/4	Fish for wireline--break out sub
24	174	10067	0	12-1/4	Fish for wireline--break out drill pipe
25	175	10067	0	12-1/4	Break out drill pipe 6999'
26	176	10067	0	12-1/4	Remove drill pipe
27	177	10067	0	12-1/4	Tag remaining drill pipe at 6958 ft
28	178	10067	0	12-1/4	Break out drill pipe at 9720 ft
29	179	10067	0	12-1/4	Attempt to remove wireball
30	180	10067	0	12-1/4	Remove wireball
<u>1979</u> Oct. 1	181	10067	0	12-1/4	Attempt to remove stuck drill pipe
2	182	10067	0	12-1/4	Wait for delivery of high-strength drill pipe
3	183	10067	0	12-1/4	Jar stuck drill pipe
4	184	10067	0	12-1/4	Jar stuck drill pipe

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
5	185	10067	0	12-1/4	Trip-in with high-set point jarring tool
6	186	10067	0	12-1/4	Successful jarring
7	187	10067	0	12-1/4	Trip-in to drill
8	188	10086	19	12-1/4	Ream-drill
9	189	10295	209	12-1/4	Drill
10	190	10341	46	12-1/4	Drill
11	191	10433	92	12-1/4	Run Maurer turbodrill to build angle
12	192	10511	78	12-1/4	Run Maurer turbodrill
13	193	10552	41	12-1/4	Run Maurer turbodrill--reaming
14	194	10552	0	12-1/4	Ream to bottom
15	195	10606	54	12-1/4	Drill--wireline broke during survey
16	196	10636	60	12-1/4	POH to recover wireline--drill
17	197	10691	55	12-1/4	Drill
18	198	10733	42	12-1/4	Drill--wireline broke during survey
19	199	10733	0	12-1/4	Ream to bottom
20	200	10736	3	12-1/4	New sandline--drill
21	201	10876	140	12-1/4	Drill--BHA stuck, freed
22	202	10926	50	12-1/4	Ream to bottom--drill
23	203	11000	74	12-1/4	Drill--ream
24	204	11097	97	12-1/4	Drill
25	205	11097	0	12-1/4	Ream to bottom
26	206	11244	127	12-1/4	Drill

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
27	207	11244	0	12-1/4	Ream to bottom
28	208	11289	65	12-1/4	Drill
29	209	11289	0	12-1/4	Ream to bottom
30	210	11295	6	12-1/4	Temperature log--drill
31	211	11306	11	12-1/4	Drill
<u>1979</u>					
Nov. 1	212	11308	2	12-1/4	Mill
2	213	11350	42	12-1/4	Drill
3	214	11421	71	12-1/4	Drill
4	215	11467	46	12-1/4	Ream to bottom
5	216	11504	37	12-1/4	Drill
6	217	11576	72	12-1/4	Drill
7	218	11616	40	11/9-5/8	Drill transition to 8-3/4-in. diam
8	219	11701	85	8-3/4	Drill
9	220	11734	33	8-3/4	Drill--junk run
10	221	11743	9	7-7/8	First core run
11	222	11794	41	8-3/4	Drill
12	223	11794	0	8-3/4	Survey
13	224	11794	0	8-3/4	Mill junk
14	225	11794	0	8-3/4	Mill
15	226	11799	6	8-3/4	Mill--junk run
16	227	11970	171	8-3/4	Drill
17	228	12111	141	8-3/4	Drill--lost cones
18	229	12111	0	8-3/4	Run magnet

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
19	230	12266	155	8-3/4	Drill
20	231	12276	10	7-7/8	Second core run
21	232	12307	31	8-3/4	Drill--survey
22	233	12500	193	8-3/4	Drill
23	234	12548	48	8-3/4	Drill--survey
24	235	12728	180	8-3/4	Drill--survey
25	236	12848	120	8-3/4	Ream--drill--survey
26	237	12856	8	7-7/8	Third core run
27	238	13000	144	8-3/4	Ream--drill
28	239	13012	12	8-3/4	Drill--survey
29	240	13176	164	8-3/4	Ream--drill--survey
30	241	13176	0	8-3/4	Replace rig's sandline
<u>1979</u>					
Dec. 1	242	13211	36	8-3/4	Ream--drill--survey
2	243	13211	0	8-3/4	Ream--tight hole
3	244	13211	0	8-3/4	Ream--tight hole
4	245	13211	0	8-3/4	Ream--tight hole--rig repair
5	246	13211	0	8-3/4	Replace rig's traveling block
6	247	13330	118	8-3/4	Resume drilling
7	248	13444	110	8-3/4	Drill--survey--ream
8	249	13454	10	7-7/8	Drill--fourth core run--7-7/8-in. bit
9	250	13464	10	7-7/8	Remove core from fourth core run
10	251	13501	37	8-3/4	Ream--survey tool lost
11	252	13628	127	8-3/4	Drill--survey tool lost

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
12	253	13657	29	8-3/4	Drill--lost bit cones
13	254	13657	0	8-3/4	Magnet run for cones--survey
14	255	13657	0	8-3/4	String ream dogleg at 3050 ft
15	256	13657	0	8-3/4	String ream
16	257	13657	0	8-3/4	Inspect drill pipe
17	258	13657	0	8-3/4	Inspect drill pipe
18	259	13657	0	8-3/4	Inspect drill pipe -- trip in hole
19	260	13756	99	8-3/4	Drill-high torque
20	261	13955	199	8-3/4	Prepare for core run no. 5
21	262	13955	0	7-7/8	Remove 7-1/2-ft core to 13963--lost circulation at √2375 ft
22	263	13955	0	8-3/4	Prepare for cementing--encountered obstruction at √1762 ft
23	264	13955	0	8-3/4	Work obstruction at √1740 ft--first TV run
24	265	13955	0	8-3/4	Work obstruction at √1782 ft--7-in. rollers
25	266	13955	0	8-3/4	Work obstruction at √1772 ft--9-5/8-in. roller--second TV run
26	267	13955	0	8-3/4	Work obstruction at √1789 ft--9-5/8-in. rollers
27	268	13955	0	8-3/4	Work obstruction with 10-3/4-in. roller--lost rollers
28	269	13955	0	8-3/4	Work obstruction at √1777 ft--third TV run
29	270	13955	0	8-3/4	Work obstruction at √1794 ft--fourth TV run

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
30	271	13955	0	8-3/4	Mill obstruction at 1796 ft-- fifth TV run
31	272	13955	0	8-3/4	Mill obstruction--sixth TV run
<u>1980</u> Jan. 1	273	13955	0	8-3/4	Work obstruction at 1798 ft
2	274	13955	0	8-3/4	Work obstruction--mill
3	275	13955	0	8-3/4	Mill and work obstruction
4	276	13955	0	8-3/4	Mill and work obstruction at 1814 ft
5	277	13955	0	8-3/4	Mill and work obstruction-- seventh TV run
6	278	13955	0	8-3/4	First cement plug attempt
7	279	13955	0	8-3/4	Second and third cement plug attempt
8	280	13955	0	8-3/4	Fourth and fifth cement plug attempt
9	281	13955	0	8-3/4	Sixth cement attempt--successful
10	282	13955	0	8-3/4	Rig breakdown
11	283	13955	0	8-3/4	Mill cement--lost circulation --seventh cementing
12	284	13955	0	8-3/4	Mill cement--lost circulation-- eighth cementing
13	285	13955	0	8-3/4	Mill cement to 1755 ft
14	286	13955	0	8-3/4	Mill cement to 1803 ft
15	287	13955	0	8-3/4	Mill cement--metal chips
16	288	13955	0	8-3/4	Mill--eighth TV run
17	289	13955	0	8-3/4	Mill--metal chips
18	290	13955	0	8-3/4	Mill--metal chips

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
19	291	13955	0	8-3/4	Mill to 1824 ft
20	292	13955	0	8-3/4	Mill--encountered obstruction at 1864 ft
21	293	13955	0	8-3/4	Mill and work casing at ~1864 ft
22	294	13955	0	8-3/4	Mill to 2273 ft
23	295	13955	0	8-3/4	Detect offset in 13-3/8-in. casing
24	296	13955	0	8-3/4	Run string reamers
25	297	13955	0	8-3/4	Run magnet
26	298	13955	0	8-3/4	Prepare to run sleeve
27	299	13955	0	8-3/4	Prepare to run sleeve
28	300	13955	0	8-3/4	Run sleeve--hit obstacle--remove sleeve
29	301	13955	0	8-3/4	Mill cement
30	302	13955	0	8-3/4	Mill--wait on geophone test
31	303	13955	0	8-3/4	Geophone test--mill
<u>1980</u>					
<u>Feb.</u> 1	304	13955	0	8-3/4	Mill obstruction at ~1800 ft
2	305	13955	0	8-3/4	Work tight spot at ~9150 ft
3	306	13955	0	8-3/4	Work tight spot at ~9400 ft
4	307	13955	0	8-3/4	Work mill through to ~10000 ft
5	308	13955	0	8-3/4	Work mill to below 11000 ft
6	309	13955	0	8-3/4	Mill to ~11,000 ft
7	310	13955	0	8-3/4	Mill--lost circulation in zone above 2350 ft
8	311	13955	0	8-3/4	Cement loss zone
9	312	13955	0	8-3/4	Drill--mill to ~1836 ft

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
10	313	13955	0	8-3/4	Mill on 13-7/8-in. collapsed casing √1845
11	314	13955	0	8-3/4	Mill cement below 2000 ft
12	315	13955	0	8-3/4	Mill to √2369--lost circulation--run temperature log
13	316	13955	0	8-3/4	Cement loss zone
14	317	13955	0	8-3/4	Mill cement to √2000 ft
15	318	13955	0	8-3/4	Mill cement to √2370 ft
16	319	13955	0	8-3/4	Mill to 11581--lost circulation
17	320	13955	0	8-3/4	Mill--run temperature log--set cementing packer √1589 ft
18	321	13955	0	8-3/4	Tag cement √1850 ft
19	322	13955	0	8-3/4	Drill cement plug
20	323	13955	0	8-3/4	Mill to 11589--lost circulation--cement
21	324	13955	0	8-3/4	Tag cement at 1775 ft--drill cement to √2165 ft
22	325	13955	0	8-3/4	Drill cement
23	326	13955	0	8-3/4	Drill cement--lost circulation at √1833--set packer and cement loss zone
24	327	13955	0	8-3/4	Drill cement packer to √1750 ft
25	328	13955	0	8-3/4	Run magnet--mill and drill to √1830 ft--set cement packer √1735 ft
26	329	13955	0	8-3/4	Cement through packer--mill
27	330	13955	0	8-3/4	Mill to 1806 ft.
28	331	13955	0	8-3/4	Mill and drill to 1814 ft

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
29	332	13955	0	8-3/4	Mill--drill--run magnet to √1829 ft
<u>1980</u> Mar. 1	333	13955	0	8-3/4	Drill--mill to √1853 ft
2	334	13955	0	8-3/4	Mill--drill to √1893 ft
3	335	13955	0	8-3/4	Drill--suspect side at √1832 ft
4	336	13955	0	8-3/4	Drill to √1981 ft
5	337	13955	0	8-3/4	Drill--ream to √2016 ft
6	338	13955	0	8-3/4	Drill--ream to √2075 ft
7	339	13955	0	8-3/4	Drill to √2104 ft
8	340	13955	0	8-3/4	Drill--lost returns--swage tight spot at √1952 ft
9	341	13955	0	8-3/4	Drill to √2218--swage to √2015 ft
10	342	13955	0	8-3/4	Work tight zone to √2000 ft
11	343	13955	0	8-3/4	Drill to 2105 ft
12	344	13955	0	8-3/4	Drill to 2300 ft
13	345	13955	0	8-3/4	Drill--jar to 2413 ft
14	346	13955	0	8-3/4	Possible sidetrack--run TV
15	347	13955	0	8-3/4	Log--sidetrack √1840 ft-- cement
16	348	13955	0	8-3/4	Run tag--rig for cementing
17	349	13955	0	8-3/4	Cement attempt
18	350	13955	0	8-3/4	Run tag--cement
19	351	13955	0	8-3/4	Mill cement to √1815 ft
20	352	13955	0	8-3/4	Mill--string mill--depth at √1936 ft

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
21	353	13955	0	8-3/4	Mill to √2054--log
22	354	13955	0	8-3/4	Drill to √2478 ft--lost circulation
23	355	13955	0	8-3/4	Nipple down for casing head installation
24	356	13955	0	8-3/4	Nipple up casing head for 9-5/8-in. casing
25	357	13955	0	8-3/4	Final drilling to 9-5/8-in. casing set point
26	358	13955	0	8-3/4	Cool down prior to running casing string
27	359	13955	0	8-3/4	Conclude cool down--prepare for casing run
28	360	13955	0	8-3/4	Run 9-5/8-in. casing string
29	361	13955	0	8-3/4	Land casing string at well head
30	362	13955	0	8-3/4	Cool down for cementing
31	363	13955	0	8-3/4	Cement 9-5/8-in. casing string
<u>1980</u>					
Apr. 1	364	13955	0	8-3/4	Cool and wait for cement to cure
2	365	13955	0	8-3/4	Cool and run temperature log
3	366	13955	0	8-3/4	Install BOP and run caliper log
4	367	13955	0	8-3/4	Drill through float equipment
5	368	13955	0	8-3/4	Drill through float shoe and to 11594 ft
6	369	13955	0	8-3/4	Mill junk below float shoe to 11604 ft
7	370	13955	0	8-3/4	Mill junk to 11608 ft
8	371	13955	0	8-3/4	Mill junk

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks
9	372	13955	0	8-3/4	Mill--pass through open hole to 11655 ft
10	373	13955	0	8-3/4	Ream--mill--magnet run
11	274	13955	0	8-3/4	Run magnet--run burn shoe
12	375	13955	0	8-3/4	Torqued burn shoe--rig down
13	376	13955	0	8-3/4	Repair rig
14	377	13955	0	8-3/4	Repair rig
15	378	13955	0	8-3/4	Repair rig
16	379	13955	0	8-3/4	Repair rig
17	380	13955	0	8-3/4	Repair rig--log hole
18	381	13955	0	8-3/4	Repair rig
19	382	13955	0	8-3/4	Repair rig
20	383	13955	0	8-3/4	Repaired rig--start trip for mill
21	384	13955	0	8-3/4	Mill to 11665 ft
22	385	13955	0	8-3/4	Magnet runs--start trip to mill
23	386	13955	0	8-3/4	Mill to 12622 ft
24	387	13955	0	8-3/4	Mill to 13928 ft--magnet run
25	388	13940	3	8-3/4	Run magnet--drill
26	389	13950	10	8-3/4	Drill
27	390	14083	133	8-3/4	Drill
28	391	14189	106	8-3/4	Drill--survey
29	392	14284	95	8-3/4	Drill
30	393	14501	217	8-3/4	Drill

Date	Days Since Spud	KB Hole Depth (ft)	Day's Footage	Hole Size (in.)	Remarks	
1980 May	1	394	14501	0	8-3/4	Part box on drill collar
	2	395	14501	0	7-7/8	Sixth core run with 7-7/8-in. bit; 3-ft core hole
	3	396	14639	138	8-3/4	Drill--run eye tool--survey
	4	397	14869	200	8-3/4	Drill
	5	398	14962	93	8-3/4	Drill
	6	399	15059	97	7-7/8 8-3/4	Seventh core run--drill
	7	400	15273	214	8-3/4	Drill--lost cone
	8	401	15273	0	8-3/4	Run magnet
	9	402	15273	0	8-3/4	Retrieve cone with magnet
	10	403	15273	0	8-3/4	Survey--pick up Maurer turbodrill
	11	404	15281	8	8-3/4	Run Maurer turbodrill
	12	405	15289	7.5	8-3/4	Run Maurer turbodrill
	13	406	15289	0	8-3/4	Run TV camera downhole
	14	407	15289	0	8-3/4	Log casing
	15	408	15289	0	8-3/4	Log casing
	16	409	15289	0	8-3/4	Log casing--release rig from EE-2

APPENDIX H

RECENT WASHOUT AND TWISTOFF FAILURES IN DRILL PIPE BEING USED IN THE NEW HOLE AT FENTON HILL A. KUMNICK

To study the excessive number of drill pipe washout and twistoff failures that have been encountered during recent drilling operations at Fenton Hill, I have closely inspected two washout failures and talked with R. Burnette about other such failures. All reported failures have occurred in 5 in. nominal o.d., 19.50 lb/ft, Grade E drill pipe. Grade E is generally used in medium depth wells, 10 000 to 15 000 ft deep, and has a minimum tensile yield strength of 75 000 psi. All of the failures have occurred in the drill pipe itself within twenty in. of a drill collar. The inside surface near the failure of the two pipes inspected showed appreciable localized corrosion in the form of round bottom pits. This corrosion could have occurred during previous use of the pipe. Both of the cracks that were inspected originated on the inside surface of the pipe at the base of a pit. The level of uniform corrosion in the failure region was determined by weight loss and found to be low. The weight of a short length of pipe containing a crack was less than 4% lower than that expected from a calculation based on nominal dimensions of new pipe.

A crack viewed in cross-section at high magnification still appears basically as a single crack. Almost no branching (i.e. crack running at 90° to the main crack) is observed. Grayish regions along the edges of the crack are suggestive of a corrosion product although this cannot be stated with certainty without a chemical analysis of this region. The drilling fluid has flowed through this crack and could be the source of the deposit.

The steel used in this pipe appears as expected for a normalized and tempered hypoeutectoid steel (i.e. <0.8%C and probably AISI 4140) normally used for Grade E pipe. The hardness was measured to be Rockwell B 98±4 and is in the proper range for the required minimum tensile yield strength of 75 000 psi.

The fact that all cracks and failures have occurred within approximately 20 in. of a drill collar is an important consideration in this problem. The region near a drill collar is subject to the maximum bending stresses as the

APPENDIX H (CONT)

drill string rotates and is most likely to exhibit failure due to fatigue. The fatigue potential is enhanced by a deviated hole because of additional bending stress and by notches because of stress concentration. Both of these factors are present to some degree in the present operation. Deviation of the hole is well known and notches are in the form of pits produced by localized corrosion. A typical drilling manual will refer to this latter situation as corrosion fatigue, i.e. a break where the notch is caused by corrosion. It is the most common cause of premature failure currently observed in drill pipe.

Since both washout and twistoff failures have been observed, the two should be discussed in the context of this proposed corrosion fatigue mechanism. Actually, the two are closely related. A washout occurs when drilling fluid is forced through the small aperture of a fatigue crack. The high velocity of the fluid causes erosion, which enlarges and rounds off the edges of the hole. When the fatigue crack grows to a point where the remaining cross section can no longer support the applied load, the pipe will twist off or fail completely.

The likelihood of stress corrosion cracking (SCC) as the cause of these failures appears unlikely for two reasons. First, as mentioned previously, the cracks do not exhibit branching which is common with SCC, and second, no evidence exists in the literature to suggest that the environment to which the drill pipe is currently exposed should produce SCC. In particular the hydroxide and carbonate levels of the fluid are much lower than those which have been shown to cause SCC in steels.

My recommendations to minimize this problem are basically related to the inspection process. Pitting to the extent visible on the inside surface of the failed pipes cannot be tolerated. Proper visual inspection should have rejected these lengths of pipe. These pits are near the ends of the pipe and no elaborate equipment is required to observe them. The use of Magnaflux on the exterior surface will not detect this type of failure until it reaches the surface, which is too late. The use of eddy current and/or ultrasonic techniques should be explored because they are capable of indicating pits or cracks

APPENDIX H (CONT)

that have not reached critical dimensions. The quality of any nondestructive inspection techniques depends critically on the operator, hence his selection is an important decision.

Whatever method of testing employed, a greater emphasis should be placed on the inspection of pipe near the ends. If the inspection procedure continues to perform poorly (i.e. failures continue), I would recommend the purchase of new drill pipe if it is available.

Energy Extraction Hole No. 2

(Kelly bushing elevation: 8720')

SCALE FOR THIS COLUMN:	SCALE FOR THIS COLUMN
1" = 50'	<u>NOT LINEAR</u> (deviated hole)

MISCELLANEOUS DATA AND COMMENTS	DRILL CUTTINGS DESCRIPTION	DRILLING RATE AVE. ft/hr OVER 10' INTERVALS			ALL DEPTHS MEASURED FROM K.B.		DEPTH ALONG WELLBORE		TRUE VERTICAL DEPTH	
		30	20	10	ft.	m.	ft.	m.		
ALL DEPTHS GIVEN IN THIS COLUMN ARE MEASURED ALONG WELLBORE.				BT TYPE and BT #						
Biotite granodiorite - An intrusive granitoid rock. This unit is the continuation of the biotite granodiorite encountered at the 8600' level in GT-2. Approximate Total Depth of GT-2.				F-8 # 82	9600			9525	2903	
	BIOTITE GRANODIORITE; light gray			S 83 J # 83		2950				
9718' - Junk Basket Recovery (J.B.R.) mainly metavolcanic chips similar to the rock of Core #2. Also some chips of granitic gneiss. These lithologies probably of minor extent or derived uphole because units were not recognized in cuttings analysis over this interval.				J-77 # 84	9700			9672	2948	
	BIOTITE GRANODIORITE GNEISS; dark gray			S 74 J # 82	9800					
				Q 96 L # 90		3000				
					9900			9819	2993	
Intrusive Rock	BIOTITE GRANODIORITE; light gray			Q 9 J L # 92 Room RR # 89 and DT J	10000	3050				
Possible fracture zone. Cuttings show abundant sulfides, epidote, and iron oxides. Biotite grains are corroded (oxidized).								9964	3037	
Approximate Total Depth of EE-1.					10100					
Possible fracture zone. Cuttings show abundant sulfides and iron oxides.	HORNBLende- BIOTITE GRANODIORITE GNEISS; brownish-gray			S 5 J # 98	3100			10107	3081	
	GRANODIORITE GNEISS; light gray to gray				10200					
Possible fracture zone. Abundant chlorite, and most of the cuttings are coated with a white alteration mineral.	LEUCOCRATIC MONZOGCRANITE GNEISS; reddish-gray			F-5 # 97	10300	3150		10252	3125	
10470' - Altered zone, x-ray diff. anal. available.	FAULT ZONE			Q 9 J L # 98 Room RR # 97 and FP 63 J # 100	10400					
10530' - Possible fracture zone. Cuttings show 25 wt. % magnetite, some sulfides also present.	GRANODIORITE GNEISS; gray				10500	3200	10394	3168		
	FAULT ZONE									
	MONZOGCRANITE GNEISS; pinkish-gray				10600					
	GRANODIORITE GNEISS; dark gray			RR # 100						
	MONZOGCRANITE GNEISS; pinkish-gray				3250		10536	3211		
	BIOTITE GRANODIORITE GNEISS; gray			J-55 # 102	10700					
	GRANODIORITE GNEISS; gray			F-5 # 103	10800	3300	10674	3253		
	MONZOGCRANITE GNEISS; pinkish-to-reddish gray				10900					
	GRANODIORITE GNEISS; brownish-gray			J-55 # 104	11000	3350	10808	3294		
11080' - J.B.R. mainly Biotite granodiorite gneiss chips, minor amounts of granitic gneiss.				M 99 TF # 105 Room RR # 104						
	FAULT ZONE				11100		10940	3335		
	BIOTITE GRANODIORITE GNEISS; gray			F-5 # 107		3400				
	HORNBLende-BIOTITE GRANODIORITE GNEISS; brownish-gray				11200					
11280' - J.B.R. shows some granitic gneiss, pegmatite, and metavolcanic. Presumably minor units, as these lithologies not recognized in cuttings analysis over this interval.	BIOTITE GRANODIORITE GNEISS; light gray			J-55 # 108 Room RR # 107			11073	3375		
11280' - Altered zone, X-ray diff. anal. available.	FAULT ZONE			S 73 J # 113	11300	3450				
	GRAND- DIOCRITE GNEISS; gray			J-77 # 114			11200	3414		
	GRANODIORITE GNEISS; light gray			RR # 113		3500				
	BIOTITE GRANODIORITE GNEISS; gray			Q 9 J L # 116	11500		11326	3452		
11587' - Bottom of the 9 5/8 in. casing.	FAULT ZONE			H-100 F # 119	11600	3550				
	BIOTITE GRANODIORITE GNEISS				11700		11454	3491		
11740' - J.B.R. dominantly Biotite granodiorite gneiss. Core 1 - Biotite granodiorite gneiss intruded by fine-grained granodiorite. Length: 143.8 cm Recovery: 78% Measured temp.: 238 ° C (LASL Temp. Sur., 6/80)	FAULT ZONE			J-99 # 122	11800	3600				
11830' - Altered zone, chemical analysis available.	FAULT ZONE			H-100 F # 125			11581	3530		
	BIOTITE GRANODIORITE GNEISS; gray				11900					
11870' - J.B.R. mostly granitic gneiss. This lithology not recognized in cuttings analysis over this interval.				H-100 F # 126		3650	11704	3567		
This lithology has been extensively altered, as white carbonate material coats most of the cuttings.	BIOTITE CHLORITE SCHIST; greenish-gray				12100					
12100' - J.B.R. dominated by Biotite granodiorite gneiss.				H-100 # 128		3700	11827	3605		
12140' - Altered zone, X-ray diff. anal. available.	FAULT ZONE									
12170' - J.B.R. dominantly Biotite granodiorite gneiss. Some leucocratic granitic chips also present. One large piece (1.0 cm across) of fault breccia material also recovered.	GRANODIORITE GNEISS; gray			H-100 F # 129	12200					
Core attempt 2. No core recovered.				S 131 # 131	12300	3750	11950	3642		
	HORNBLende- BIOTITE GRANODIORITE GNEISS; dark gray			7 GA # 132	12400					
	HORNBLende GRANODIORITE GNEISS; gray					3800	12073	3680		
	GRANODIORITE GNEISS; gray				12500					

Energy Extraction Hole No. 2

(Kelly bushing elevation: 8720')

SCALE FOR THIS COLUMN: 1" = 50'

SCALE FOR THIS COLUMN: NOT LINEAR
(deviated hole)

MISCELLANEOUS DATA AND COMMENTS	DRILL CUTTINGS DESCRIPTION	DRILLING RATE AVE. ft/hr OVER 10' INTERVALS			DEPTH ALONG WELLBORE		TRUE VERTICAL DEPTH	
		30	20	10	ft.	m.	ft.	m.
ALL DEPTHS GIVEN IN THIS COLUMN ARE MEASURED ALONG WELLBORE:				BT TYPE and BT #				
	GRANODIORITE GNEISS; light gray			7 GA # 132	12500			
	FAULT ZONE							
	BIOTITE GRANODIORITE GNEISS; gray				12600		12196	3717
				7 GA # 133		3850		
12720' - J.B.R. dominately Biotite granodiorite gneiss.					12700			
12740' - Altered zone, chemical analysis available.	FAULT ZONE						12319	3755
	BIOTITE GRANODIORITE GNEISS; gray			7 GA # 134	12800	3900		
This metavolcanic unit has been extensively intruded by granodioritic material over its entire thickness.	METAVOLCANIC; dark gray							
Core 2 - Mafic metavolcanic intruded by granodiorite. Length: 223.3 cm Recovery: 91% Measured temp.: 283 ° C (LASL Temp. Sur., 8/80)	FAULT ZONE				12900		12442	3792
				BJA # 136		3950		
This metavolcanic unit has been extensively intruded by granodioritic material over its entire thickness.	METAVOLCANIC; dark gray				13000		12565	3830
13010' - J.B.R. dominately metavolcanic chips.								
	BIOTITE GRANODIORITE; light gray			7 GA # 137	13100	4000		
Intrusive Rock								
13180' - Altered zone, X-ray diff. anal. available.								
13190' thru 13212' - Junk Basket Recoveries in this interval mainly produced Biotite granodiorite (intrusive, granitoid)	BIOTITE GRANODIORITE; light gray			7 GA # 138 # 139	13200		12688	3867
	METAVOLCANIC; dark gray							
Intrusive Rock				RR # 138	13300	4050		
13330' - J.B.R. mainly Biotite granodiorite gneiss.	BIOTITE GRANODIORITE; light gray						12811	3905
Intrusive Rock								
	BIOTITE GRANODIORITE GNEISS; gray			H-100 # 141	13400			
13430' - J.B.R. dominately Biotite granodiorite (intrusive, granitoid).						4100		
Core 3 - Biotite granodiorite (w/granitoid texture). Length: 123.3 cm Recovery: 41% Measured temp.: 277 ° C (LASL Temp. Sur., 8/80)	BIOTITE GRANODIORITE; light gray				13500		12935	3943
				7 GA # 143				
This unit has been extensively intruded by granodioritic material over its entire thickness.	BIOTITE CHLORITE SCHIST; greenish-gray				13600	4150		
13650' - J.B.R. dominately Biotite granodiorite (intrusive, granitoid).	BIOTITE GRANODIORITE; light gray						13080	3981
	METAVOLCANIC; greenish-gray				13700			
	LEUCOCRATIC MONZOGRANITE; very light gray							
A possible Intrusive Rock						4200		
	BIOTITE MONZOGRANITE GNEISS; light gray			7 GA # 146	13800		13183	4018
13900' - J.B.R. shows chips very similar to the rock of Core 4 (mafic rich gneiss).					13900			
						4250	13307	4066
Core 4 - Biotite-amphibole gneiss intruded by biotite granodiorite (w/granitoid texture). Length: 28.7 cm Recovery: 100% Measured temp.: 298 ° C (LASL Temp. Sur., 8/80)	BIOTITE AMPHIBOLE GNEISS; dark gray			7 GA # 146	14000			
					14100	4300	13432	4084
					14200			
							13555	4132
	BIOTITE GRANODIORITE; gray				14300	4350		
Intrusive Rock								
	BIOTITE AMPHIBOLE GNEISS; dark gray			7 GA # 167 (RR # 165)			13678	4169
	BIOTITE GRANODIORITE GNEISS; gray				14400	4400		
Core 5 - Biotite - amphibole gneiss. Length: 100.5 cm Recovery: 100% Measured temp.: 302 ° C (LASL Temp. Sur., 8/80)	BIOTITE AMPHIBOLE GNEISS; dark gray				14500		13801	4207
					14600	4450		
					14700		13924	4244
				7 GA # 169		4500		
					14800		14047	4282
						4550		
Core 6 - Biotite granodiorite gneiss intruded by fine-grained granodiorite. Length: 48.0 cm Recovery: 40% Measured Temp.: 313 ° C (LASL Temp. Sur., 8/80)	BIOTITE GRANODIORITE GNEISS; gray				14900			
					15000		14170	4319
				7 GA # 171	15100	4800		
							14293	4357
					15200			
						4850		
					15300		14416	4394