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**Testing, Planning, and Redrilling of
Geothermal Test Hole GT-2, Phases IV and V**

University of California

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TESTING, PLANNING, AND REDRILLING OF GEOTHERMAL TEST HOLE GT-2, PHASES IV AND V

by

Roland A. Pettitt

ABSTRACT

Holes GT-2 and EE-1 comprise the two deep drill holes of the Los Alamos Hot Dry Rock Geothermal Energy Extraction Experiment. EE-1 had been directionally drilled to intersect a hydraulic fracture extending outward from near the bottom of GT-2, thus completing the underground circulation loop. After the drilling of EE-1, a 16-month period of experimental testing ensued to determine the characteristics of the reservoir. This period is designated as Phase IV and includes work done in GT-2 and EE-1. As a result of this testing, it was determined that parallel fracture zones existed at the bottoms of both holes, and that the impedance to flow between the holes was too high for a meaningful flow experiment. A plan was then adopted to directionally drill out of GT-2 at a depth of about 2600 m (8500 ft) to intersect the fracture zone near the bottom of EE-1 to create a better connection. The directional drilling strategy, cementing practices, bit selections, coring procedures, and logging results comprise the Phase V work.

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I. INTRODUCTION

At sufficient depth, rock that is hot enough to be potentially useful exists everywhere; in many places it is at depths shallow enough to be reached at reasonable drilling costs. Geothermal heat is present and accessible even where geothermal fluids are absent. The heat contained in the hot, relatively impermeable "dry" rock of the earth is universally distributed so that it could, in time, contribute significantly to the world's energy supply. For the past 5 yr, the Los Alamos Scientific Laboratory (LASL) has been actively investigating the

potential for and problems associated with extracting geothermal energy from regions of the western US that contain hot, but essentially dry rock at moderate depth.

On the basis of previous studies, surveys, and field experiments,¹⁻³ a site on the Jemez Plateau west of Los Alamos was selected as an appropriate location for the first hot dry rock energy experiment. It has been officially identified as the "Fenton Hill Site," or TA-57 (LASL Technical Area 57). LASL is located on the eastern flank of the Jemez Mountains, about 50 km (30 mi) by road from Fenton Hill. The Jemez Plateau is part of the western arm of the Rocky Mountains, which extend into northern New Mexico (Fig. 1). As a result of relatively recent volcanism, a large amount of heat is still retained in rocks underlying the entire area within a few kilometers of the surface.

II. SUMMARY OF PRECEDING WORK

A. Hole GT-2

Geothermal Test Hole No. 2 (GT-2) was the first deep exploratory hole drilled to confirm the suitability of the Fenton Hill site for further development of the hot dry rock geothermal energy experiment. Drilling began in GT-2 on February 17, 1974, and was completed to a depth of 2042.2 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 was 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. Following this work, the hole was deepened to 2932 m (9619 ft). The bottom-hole temperature was 197°C (387°F). Various diagnostic logging operations were performed after the drilling was completed. A 185-m- (608-ft-) long liner assembly with a polished-bore receptacle (PBR) at its upper end was then placed and cemented in the bottom section of the hole, with a string of 11.4-cm and 14-cm (4-1/2-in. and 5-1/2-in.) casing extending to the surface.

Detailed accounts of the planning, drilling, logging, and testing work performed in GT-2, Phases I, II, and III, have been presented in previous reports.⁴⁻¹¹

B. Hole EE-1

The second hole, Energy Extraction Hole No. 1, is located 77 m (252 ft) northeast of GT-2. Drilling began in May 1975 and was completed in October at a

depth of 3064 m (10 053 ft) and a bottom-hole temperature of 205.5°C (402°F). EE-1 was cased to 1957 m (6420 ft) with three strings of casing, the deepest being 27.3 cm (10-3/4 in.) in diameter.

Directional drilling techniques were used below this casing to angle EE-1 toward the fracture at the bottom of GT-2. The hole was drilled through a 205° spiral, turning counterclockwise from an initial northwest heading to a northeast heading. On October 14, 1975, the fracture was intersected, creating for the first time a manmade connection between two drill holes in hot, nearly impermeable basement rock. After the intersection was completed and circulation was established, EE-1 was cased to 2926 m (9600 ft) with a 19.4-cm (7-5/8-in.) casing for subsequent pressurized flow and heat extraction experiments.

Detailed accounts of the planning, drilling, logging, and testing work performed in EE-1, Phases I and II, have been presented in previous reports.¹¹⁻¹²

C. Geology

The predominant Precambrian rock in both holes is banded granitic gneiss. In one section, biotite schists are interlayered with the gneiss, which is intruded by unfoliated monzogranite dikes. A relatively extensive and homogeneous biotite-granodiorite body was encountered at depth. Drill cores show numerous fractures, usually well sealed or healed.

For a detailed description of the geologic cores in GT-2 and EE-1 see Ref. 13.

III. HOLE GT-2, PHASE IV

A. Experiments and Testing

After the completion of drilling in EE-1, a long period of experimental testing ensued, from November 6, 1975 until the beginning of redrilling in GT-2 in April 1977. This period has been designated as Phase IV and includes work done in GT-2 and EE-1. Many of the techniques, equipment, and instruments required to determine the extent and characteristics of a hot dry rock reservoir at a depth of 3 km (10 000 ft) and at a temperature of 200°C (392°F) did not exist at the beginning of the project. Only after both holes had been completed could these tools and techniques be developed.

A brief summary of the major field experiments conducted during this phase of the work is included as Appendix A. These experiments can be roughly divided into the following categories.

1. Locating and Mapping Subsurface Fractures. Much effort was directed toward development of fracture-mapping methods. Several field techniques, such as monitoring of surface seismic signals during downhole fracturing, the use of surface and near-surface active sources (Dinoseis and dynamite) combined with downhole acoustic detectors, and the use of a borehole televiewer by the US Geological Survey, were tried before we determined that downhole acoustic and electromagnetic detection techniques were required.

2. Instrumentation Development. Suitable detection equipment had to be designed, built, and field tested to accommodate the fracture-mapping techniques that were being tested during this period. Also, appropriate data analysis methods had to be developed. The downhole instruments, which were required to operate under the extreme conditions of 200°C and 400 bars, included acoustic detectors, a mechanical acoustic source, a chemical detonation acoustic source, temperature probes, self-potential (SP) and induced potential (IP) probes, water samplers, electromagnetic ranging devices, and downhole orienting tools.

3. Borehole and Fracture Impedance Testing. Determination of the impedance (resistance to flow) of the GT-2/EE-1 fracture system was of primary importance in determining if a meaningful flow experiment could be conducted. The initial flow impedance of the system was about 1320 bars/liter/s (1200 psi/gpm), but decreased to a minimum of about 30 bars/liter/s (27 psi/gpm). Many experiments were conducted to obtain refined values of the impedance, and to attempt to decrease it. Also, pressure-flow and fluid residence-time distribution studies were made to measure properties of the downhole system, such as the product of the effective fracture surface area and the square root of the permeability ($A\sqrt{k}$), and the volume of the circulating fluid in the fracture.

During Experiment 133 on July 19, 1976, a breakthrough of fluid flow into the GT-2 annulus occurred while pumping into EE-1. It appeared that the flow was entering the annulus between depths of 2747.8 and 2773.7 m (9015 and 9100 ft), probably coming up from the fracture through the cemented space outside the scab liner. Because of this leak, the impedance of the system decreased from a pre-experiment value of 110 bars/liter/s (100 psi/gpm) to 33 bars/liter/s (30 psi/gpm).

4. Chemical Leaching Experiment. Of special significance were two leaching experiments (Nos. 137 and 138) conducted November 1-18, 1976, in an attempt to reduce the impedance by dissolving and removing silica (quartz) from the fractured region.

a. Preleaching Experiment No. 137. The primary objective of this experiment was to provide a "background" flow for the forthcoming chemical leaching experiment. Secondary objectives were to obtain time variations of the GT-2 effluent water chemistry and long-term flow impedance values between GT-2 and EE-1, to determine fracture volume and residence time using a sodium-fluorescein dye tracer, and to test the water treatment equipment.

Flow for the experiment began on November 4, when EE-1 was pressurized to 8.3 MPa (1200 psi) at a pumping rate of 163 liters/m (43 gpm). The outflow from GT-2 was piped through a 1-MW heat exchanger, two sieve strainers, activated alumina and charcoal filters (Fig. 2), and into the GT-2 reserve pond for chemical testing before it was discharged down a nearby water course. At 7:00 am on November 6, 15 liters (4 gal) of sodium-fluorescein dye diluted with 570 liters (150 gal) of water were injected into the system. The first coloration appeared in the GT-2 effluent 24 h later, and in 48 h essentially all the dye had passed through the system. During this time, the pumping rate into EE-1 gradually decreased to 76 liters/m (20 gpm) while a wellhead pressure of 8.3 MPa (1200 psi) was maintained.

The objectives achieved in the preleaching experiment were:

1. A steady-state impedance of 83 bars/liter/s (75 psi/gpm) was observed for over 175 h, while pumping 700 m^3 (250 000 gal) from EE-1 to GT-2. This

Fig. 1.

Major structural features and area of investigation in north-central New Mexico.

Fig. 2.

Sieve strainers in foreground, alumina and charcoal filter in back, for Experiments 137 and 138.

corresponded to a 57-liters/m (15-gpm) flow out of the vented GT-2 wellbore with a constant 8.3 MPa (1200 psi) surface injection pressure maintained at EE-1.

2. A preleaching sodium-fluorescein dye tracer study was successfully implemented with the mean system volume and residence-time distribution being determined.

3. A steady-state level of effluent fluid composition was reached before any sodium carbonate (Na_2CO_3) was injected for the leaching experiment.

4. Water circulated through the GT-2/EE-1 system during the experiment was successfully treated with activated alumina and charcoal filters to remove fluoride, hydrogen sulfide, sodium-fluorescein dye, and other organic contaminants, as required by Forest Service and Environmental Protection Agency regulations.

b. Leaching Experiment No. 138. Pumping of a 1-N Na_2CO_3 solution into EE-1 began at 5:00 pm on November 11, without interruption of pumping from the preleaching phase. The flow rate gradually increased to 334 liters/m (88 gpm) on November 12 at a constant EE-1 wellhead pressure of 8.3 MPa (1200 psi), then gradually declined to 34 liters/m (9 gpm), whereupon it began to increase again, while the EE-1 wellhead pressure remained constant. After about 70 m^3 (25 000 gal) of the carbonate solution had been injected, the GT-2 outflow decreased to 46 liters/m (12 gpm) and remained constant at that level.

A significant increase in bicarbonate appeared in the GT-2 effluent at 12:30 pm on November 12; the fluoride content at that time was 20 ppm. By 2:30 pm the silica content of the effluent had started to increase from a low of 200 ppm. By 10:00 pm the fluoride content had increased to 140 ppm and the silica to 1400 ppm. The fluoride content eventually peaked at 190 ppm and the silica at 2500 ppm.

At 12:30 pm on November 12, a total of 181.4 m^3 (47 866 gal) of Na_2CO_3 solution had been pumped into EE-1 and the injection of water was begun. A 418-liter (110-gal) batch of sodium-fluorescein dye solution was injected at 10:30 am on November 13; the dye reached peak concentration in the effluent at 6:30 am on November 15. EE-1 was shut in on November 17, after about 1615 m^3 (426 000 gal) had been injected in both experiments.

c. Conclusions. As a result of the leaching experiment, the impedance between the two holes actually increased from a value of about 83 bars/liter/s (75 psi/gpm) to between 100 - 111 bars/liter/s (90 - 100 psi/gpm). A chemical or physical effect may have caused this drop in flow, but most likely a fraction of

the flow paths between GT-2 and EE-1 was closed or plugged. The increase in impedance restored the system to its original state before the breakthrough into the GT-2 annulus during Experiment 133.

About 1000 - 2000 kg (1 - 2 tons) of silica (SiO_2) were dissolved from the reservoir during the experiment. A peak concentration of 2500 ppm SiO_2 was observed as compared to an ambient level of 220 ppm when water was circulated. The postleaching dye study indicated that no significant change in either system volume or residence-time distribution occurred. The ultimate objective of reducing the downhole flow impedance was not achieved, and plans for a redrilling operation continued.

5. Gyroscopic Surveys. As we realized that the task of locating the fracture system was more difficult than first anticipated, steps were initiated to accurately determine the relative positions of the bottoms of the boreholes. Previous magnetic and gyroscopic surveys had produced conflicting and unreliable results, caused by magnetic anomalies in the granitic rock and the high temperature and hydrostatic pressure in the holes. Figure 3 shows the plan view of the assumed drilling paths of the two holes after directional drilling in EE-1 had been completed on October 12, 1975.

During the summer of 1976, R&D contracts were negotiated with Eastman Whipstock and with Sperry-Sun, both of Houston, Texas, for development of gyroscopic survey tools capable of operating at temperatures over 200°C (392°F).

The basic design of both tools was nearly the same in that each used a vacuum heat shield and a Cerrobend metal heat sink to protect the gyro and batteries. The Eastman package was 12.7-cm (5-in.) o.d. and featured a surface readout of internal temperature and operating voltage. The Sperry-Sun tool was 15.2-cm (6-in.) o.d. and was completely self-contained.

a. Eastman Whipstock Survey. On January 28, 1977, the survey team, consisting of an electrical engineer and a logger, arrived from Houston. Logging began in EE-1 (see Fig. 4) but the first two runs ended in failure because of leaky O-ring seals. The seals were then coated with Krytox 240 grease and the electrical connectors encapsulated in RTV sealant. Successful runs were then made in both holes with a maximum internal tool temperature of 45°C (113°F). Both holes were logged at 30-m (100-ft) intervals going down and 152-m (500-ft) intervals coming out.

From plots of the hole surveys, we learned that a displacement of about 27 m (90 ft) existed between GT-2 and EE-1 at a depth of 2895.6 m (9500 ft). Because

Fig. 3.

Plan view of assumed directional drilling paths in GT-2 and EE-1. Depths measured from elevation taken at casing flange near ground level.

Fig. 4.

Eastman Whipstock gyro tool being readied for insertion into EE-1.

this distance could not be verified by the acoustic ranging data or the electromagnetic measurements, a check was made of the original bearings. A 30° error was found in the EE-1 bearing, resulting from an iron pipe buried under the snow near the survey point. When this correction was applied, the distance between the two holes at 2895.6 m (9500 ft) was 14.0 m (46 ft).

b. Sperry-Sun Survey. On February 14, two crews of three men each arrived with the Sperry-Sun tool. They ran two surveys (Fig. 5) in each hole, mostly at 7.6-m (25-ft) stations, without any problems with the tool. The maximum internal temperature was less than 82°C (180°F). The two surveys in GT-2 produced almost identical results; the two surveys in EE-1 gave bottom-hole locations about 6 m (20 ft) apart.

c. Results. The plots of the logs for both surveys are shown in Fig. 6. The distance of 13.3 m (43.5 ft) between the two boreholes at 2895.6 m (9500 ft) agrees well with measurements made by other methods. Both tools performed well under the conditions they were designed for and produced results that were within the specified tolerances.

Fig. 5.
Foresight being taken with Sperry-Sun
gyro tool in GT-2.

Fig. 6.
Plot of bottom-hole sections of gyro-
scopic surveys. EE-1 runs 1 and 2, 3
and 4; GT-2 runs 5 and 6 were conducted
by Sperry-Sun; the remaining two were
conducted by Eastman Whipstock.

IV. REDRILLING PLAN

A. Conclusions from Tests

As a result of the tests and experiments described in the preceding section, the following conclusions were reached.

- Nearly parallel fracture zones existed in GT-2 and EE-1 at about the 2926.1-m (9600-ft) depth.
- The impedance to flow between the fracture zones was too high to conduct a meaningful heat exchanger experiment.
- The high impedance could not be relieved by chemical leaching.
- Through conferences with LASL explosives experts, we determined that the impedance probably could not be reduced by using conventional explosive charges. (Enough shaped charges, sufficiently insulated against the heat

of the hole, could not be inserted to fracture rock more than 0.3 or 0.6 m [1 or 2 ft] from the borehole.)

After the gyroscopic surveys confirmed the relative positions of the bottoms of the boreholes, and the vertical extent of the fracture zones had been determined by seismic experiments, redrilling became an increasingly favorable option.

B. Redrilling Task Force

Preliminary studies for a redrilling program began in June 1976, and specifications for the operations were written in July 1976. As additional testing progressed, a small group was formally organized in January 1977 to study further the problems of redrilling and to make recommendations for directionally drilling out of one borehole to intersect the fracture zone near the bottom of the other. This group of seven members, known as the Redrilling Task Force, included the directional drilling consultant who had conducted the Dyna-Drill operations in EE-1.

C. Recommendations

After study and discussions, two plans were submitted.

1. Plan I. Three drilling paths from GT-2 into the fracture systems originating from EE-1 at ~2770 m (9100 ft) were considered.

a. Path A. Kick off in GT-2 at ~2590-m (8500-ft) depth to intersect the fracture originating from EE-1.

b. Path B. If no connection is observed in Path A, kick off from GT-2 in the Path A hole at ~2650-m (8700-ft) depth, and intersect the fracture below the point of origin in EE-1.

c. Path C. If either Path A or B is successful, a third redrill might be undertaken to obtain a better position for a GT-2 exit point on the heat-transfer surface.

2. Plan II. If none of the above is successful, drill from GT-2 to intersect the GT-2 fracture at 2736 m (8975 ft), and extend drilling to 2896 m (9500 ft). Move the drilling rig to EE-1, and drill through the GT-2 fracture and on to 3018 m (9900 ft). If a low-impedance connection is not obtained, then the drilling extensions would provide an area in which new fracture systems could be initiated.

Appendix B contains the report summary of the Redrilling Task Force.

V. DRILLING HISTORY

A. Contractural Agreements

More than 20 separate contracts were issued to cover the work associated with redrilling GT-2. The major contracts are listed and described below.

1. Drilling Rig Contracts

a. Pulling Rig. Before the surveys and experiments could be performed that would correctly determine the relative positions of the boreholes and fracture zones, the pressurizing string of high-pressure casing⁹ had to be pulled from GT-2. A contract was signed with DA&S Oil Well Servicing Company of Hobbs, New Mexico, to remove 518 m (1700 ft) of 14.0-cm (5-1/2-in.) casing and 2207 m (7240 ft) of 11.4-cm (4-1/2-in.) casing, plus the polished-bore mandrel.

The truck-mounted mobile pulling rig arrived at the site on December 17, 1976 (Fig. 7). The mandrel was pulled out of the PBR assembly with no difficulty on the following day. By December 20, the casing and mandrel were completely out of the hole (Fig. 8), and the pulling rig was dismantled and off location.

Fig. 7.
Pulling rig at GT-2 to remove casing
pipe and PBR mandrel.

Fig. 8.
Close-up of PBR mandrel assembly, show-
ing damaged chevron seals.

b. Major Drilling Contract. In August 1976, bids were solicited from 10 drilling contractors. Because of the great upturn in drilling activity in the Rocky Mountain region caused by the increase in the regulated wellhead price of "new" refined gas, only two contractors submitted bids. The bids were evaluated in September and October; Noble Drilling Corporation of Midland, Texas, was the acceptable low bidder. In February 1977, a contract was signed with Noble Drilling and preparations were begun to move a drilling rig to Fenton Hill.

The specifications of the drilling rig are listed in Appendix C.

c. Contract Items. The contract with Noble Drilling Corporation 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. The contract provided for 80 days of operations, and the work was completed in that time. However, certain operations in the original contract, such as pulling the pressurizing string of casing and drilling out the cement after setting the final casing, were performed by others.

d. Third-Party Contracts. The contract item for subcontractor-acquired property and services (special items and services) provided for the 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.

2. Consultant Services

a. Drilling Manager. Because of the complexity of the operations anticipated in sidetracking out of one hole and intersecting the fracture in the bottom of the other, the services of a drilling manager were required. A purchase order contract was awarded to Minerals Management, Division of Scientific Software, Denver, Colorado, to furnish these services. The contract provided for the continuous on-site supervision by an experienced drilling engineer, to direct the operation of the drilling rig and crews and to coordinate these drilling-related activities with numerous LASL-directed activities. The job description for this drilling manager is fully detailed in Appendix D.

b. Cementing Engineer. A separate purchase order contract was awarded to Minerals Management for the services of an engineer to plan and advise on the sizing, installation, and cementing procedure of the casing in GT-2. Because of the importance of obtaining a durable cementing of the casing, and considering

the possible downhole temperature fluctuations during pumping and testing of the underground reservoir system, an analysis by an outside authority (not employed by a cementing contractor) was considered necessary.

On the recommendation of this cementing engineer, the LASL-owned 21.9-cm (8-5/8-in.) casing, originally intended to be used, was replaced with 19.4-cm (7-5/8-in.) casing.

c. Directional Drilling Engineer. A purchase order contract was also awarded to Roy Lemons, Los Lunas, New Mexico, for services in directing the Dyna-Drill operations. The same directional driller who supervised the drilling of EE-1 was on-site at Fenton Hill during all of the directional drilling in GT-2.

3. Drill Bits. The major suppliers for bits were the Smith Tool Division of Smith International, Inc., for tricone rock bits, and Christensen Diamond Products, for diamond core bits.

4. Packers. In August 1976, a sole-source purchase request was issued to Lynes United Services, Houston, Texas, for the fabrication of six open-hole high-temperature packer elements and two mandrel assemblies. The fabrication and testing of the packers was completed at the Lynes facility in November, and the packers were subsequently sent to Hobbs, New Mexico, for storage until scheduled for use at Fenton Hill.

Two complete tools were made up. Each was about 2.6 m (8-1/2 ft) long, with a 0.9-m (3-ft) -long inflatable rubber section, 21.9-cm (8-5/8-in.) o.d., over a braided steel wire backing. These packers were the first to be specifically designed for high-temperature geothermal applications, and they were factory-tested at 204°C (400°F) for 15 h at 15.9 MPa (2300 psi).

5. 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 and experiments, remove and repair fences, and maintain the reserve pond.

B. Drilling Progress

1. Mobilization and Drilling Crews. On March 29, Noble Drilling Corporation began moving the equipment for Drilling Rig No. N115 onto the location. The sub-structure was completed and the Kelly bushing was set on April 1. The elevation of the top of the Kelly bushing was 2656.3 m (8714.9 ft) above mean sea level, and all depths in this report were measured from that point. Erection of the drilling rig was completed on April 5 (Fig. 9).

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 came back to work on the shift preceding the one that they had previously worked.

One tool pusher was employed, who lived at the site in a trailer provided by Noble.

2. Hole GT-2A. The first drill pipe was picked up on April 6, the bottom of the open-ended string was set at a depth of 2580.1 m (8465 ft), and the hole was circulated for 4 h. Placement of the cement plug before the first side-tracking attempt was completed at 7:20 am on April 7 by Halliburton Cementing Services of Farmington, New Mexico; 125 sacks of Class B cement with 40% silica flour and appropriate admixtures were used (Fig. 10).

The hole was re-entered to face off the cement plug on April 8 with a Smith 24.5-cm (9-5/8-in.) 9JA button bit. (See Appendix E for the complete bit record.)

Fig. 9.
Noble Company drilling rig on location
at GT-2, viewed from north.

Fig. 10.
Halliburton cementing truck from drill-
ing rig catwalk.

The cement was drilled out to a depth of 2518.6 m (8263 ft), the drill pipe was pulled from the hole, and a Dyna-Drill assembly with a 2° bent sub was run with the same type bit. Directional orientation of the assembly was determined by use of Eastman Whipstock's single-shot directional survey equipment. Although the Dyna-Drill had operated satisfactorily at the surface, it would not drill at the bottom of the hole. When pulled, it was found to be plugged with cement cuttings.

Drilling began again at 6:15 pm on April 9 with a new Dyna-Drill assembly. After 7 h of drilling, a depth of 2542.6 m (8342 ft) had been reached, but the drill was still in the original hole, having been unable to sidetrack into the granitic sidewall. The assembly was started out of the hole and Halliburton was called for a recementing operation using a harder mix design with less retarder and less water.

The top of the second cement plug, placed on April 10, was encountered at 2468.6 m (8099 ft) and was drilled out to a depth of 2488.1 m (8163 ft). At 5:00 am on April 12, a new Dyna-Drill assembly, consisting of a 1-1/2° bent housing with a 1-1/2° bent sub above and a Security 25.1-cm (9-7/8-in.) H7SGJ toothed bit, was run in the hole. About 25 - 30 m (75 - 100 ft) of cement fill were encountered on top of the plug. The bit would not turn; the assembly was pulled, and the two collars above the Dyna-Drill were found to be plugged with cuttings. A straight drilling assembly was made up with the same toothed bit and run back down the hole. A mud mixture of Baroid Quikgel and soda ash was pumped in to lift the cement cuttings out of the hole. The use of this mixture became standard practice for cleaning and circulating the hole at the end of each drilling run. By 8:00 am on April 13, the hole had been cleaned to 2488.1 m (8163 ft) and was being circulated.

The same Dyna-Drill assembly with a new Security 25.1-cm (9-7/8-in.) toothed bit was made up and run down the hole. It was oriented and then rotated for 15 min on bottom. Drilling began at a controlled penetration rate of 0.3 m/h (1 ft/h) with a weight of 1.4 Mg (3000 lb) on the bit. At a depth of 2491.1 m (8173 ft), drilling was stopped and the bit rotated for 1-1/2 h. Drilling then began again at a penetration rate of 0.6 m/h (2 ft/h) with a weight of 2.7 Mg (6000 lb). At a depth of 2494.2 m (8183 ft), the bit had not begun to sidetrack out of the hole. Drilling was halted and the assembly was pulled. The toothed bit showed evidence of extreme wear on the outer edges of the outside row of teeth and gauge buttons, as if it had been trying to cut into the side of the hole (Fig. 11).

The same Dyna-Drill assembly with a Christensen 25.1-cm (9-7/8-in.) side-cutting diamond bit was next run down the hole. After the tool was oriented, drilling progressed slowly. About 5 m (15 ft) were drilling, to a depth of 2498.8 m (8198 ft), presumably into the granitic sidewall. Trouble with the Dyna-Drill motor prevented further drilling, and the assembly was started back out of the hole at 5:30 am, April 15.

The beginning of a side cut was thought to have been accomplished, and a Smith 24.5-cm (9-5/8-in.) 9JA bit and three-point reamer assembly were started back down (no Dyna-Drill). The penetration rate was about 0.3 m/min (1 ft/min); after drilling to 2505.5 m (8220 ft), the bit apparently was still cutting cement in the original hole. A single-shot survey confirmed this suspicion, and the assembly was withdrawn from the hole.

A specially designed Christensen MD-43GST 24.5-cm (9-5/8-in.) side-cutting diamond bit (Fig. 12a) was then run in on the same Dyna-Drill with a 2° bent sub. Drilling progressed to 0.3 m/h (1 ft/h) to a depth of 2508.2 m (8229 ft). The load on the bit increased slowly over the period, and a few granitic chips showed in the cuttings. When the bit was pulled, most of the diamonds on the outside cutting surface were completely worn away, and large pieces of the matrix material had been gouged out — evidence of extremely hard usage (Fig. 12b). We believed that a shoulder had been cut into the granitic wall at this depth. Two more runs with the Dyna-Drill and diamond bits at a penetration rate of 0.5 m/h (1.5 ft/h) and a load of 9.1 Mg (20 000 lb) took the depth to 2513.4 m (8246 ft). When the last bit was pulled, there was evidence of wear across the full face.

Fig. 11.
Steel-toothed bit used for sidetracking attempt. Note extreme wear on outside edge.

(a)

(b)

Fig. 12.

Specially designed side-cutting diamond bit, MD-43GST, (a) before drilling and (b) after drilling 3 m (9 ft).

Fig. 13.

Side-cutting bit (MD-331), with different design characteristics, advanced the hole to 2518.2 m (8262 ft).

On April 19, a Security 24.5-cm (9-5/8-in.) H10J bit with three-point reamer and Monel collar was run in the hole to obtain a survey as close to the bottom of the new hole as possible. Drilling with this assembly continued to 2515.2 m (8252 ft). Another Dyna-Drill run with a diamond bit of different design (Fig. 13) on April 20 and 21 advanced the hole to 2518.3 m (8262 ft). Examination of the bit continued to show wear across the center of the cutting face.

A Smith 24.5-cm (9-5/8-in.) 9JA bit with reamer and Monel collar was again run in. Two consecutive single-shot surveys indicated that the new hole was drifting back toward the bearing of the original hole. An attempt was made to increase the angle of the new hole by drilling with this stiff assembly. Drilling appeared to be in granitic rock for about 2 m (7 ft), and then the penetration rate increased to 0.3 m/min (1 ft/min), indicating the drill was back in the old hole. Drilling was halted at 2523.7 m (8280 ft) and plans were made to underream the hole to provide a ledge for sidetracking.

On April 23, the hole was enlarged to 40.6 cm (16 in.) (Fig. 14) from 2471.9 to 2475.0 m (8110 to 8120 ft). The following day Halliburton Cementing Services placed a cement plug of 150 sacks, with red color additives, through open-ended drill pipe at a depth of 2450.6 m (8040 ft).

The cement plug was faced off to a depth of 2471.9 m (8110 ft) on April 25, a Dyna-Drill assembly with a Christensen 20.0-cm (7-7/8-in.) side-cutting diamond bit was run in, and drilling progressed to 2476.8 m (8126 ft).

It first appeared that the bit had missed the ledge cut by the underreaming assembly, but a recheck of the depth calculations indicated that the drilling may have stopped just short of this point. A new 20.0-cm (7-7/8-in.) diamond bit with the same Dyna-Drill assembly was run in. After drilling ahead to 2477.4 m (8128 ft), the load began to increase. Drilling progressed at 0.3 - 0.6 m/h (1 - 2 ft/h) with 2.3 - 3.6 Mg (5000 - 8000 lb) on the bit. At 2481.1 m (8140 ft), the assembly was pulled and the hole was enlarged to a diameter of 24.5 cm (9-5/8 in.) with a Smith 9JA bit, to a depth of 2480.8 m (8139 ft).

A 24.5-cm (9-5/8-in.) Christensen diamond bit with the Dyna-Drill assembly was run down the hole. Drilling progressed for 0.3 m (1 ft), to a depth of 2481.1 m (8140 ft). No further downward progress could be made, in spite of applying up to 9.1 Mg (20 000 lb) of load. The bit was then pulled from the hole. It appeared to be in good condition; however, several small [0.6-cm (1/4-in.)] pieces of granitic rock were lodged in the grooves on the face of the bit. A piece of loose rock may have been in the bottom of the hole, rolling around under the diamond bit and preventing further drilling.

A 24.5-cm (9-5/8-in.) Smith 9JA button bit and Dyna-Drill assembly was run in on the morning of April 29 to clean out the bottom of the hole. After drilling about 0.3 m (1 ft), it was pulled and a new 24.5-cm (9-5/8-in.) Christensen diamond bit was run in on the Dyna-Drill. At 3:00 am the following morning, the bit quit cutting at 2482.3 m (8144 ft) with a maximum load of 4.5 Mg (10 000 lb).

The cuttings showed increasing amounts of granitic chips. The diamond bit was pulled and a 24.5-cm (9-5/8-in.) Smith 9JA bit was started back in. Drilling began at 2:15 pm with a load of 0.9 Mg (2000 lb). By 4:00 pm, a depth of 2483.8 m (8149 ft) had been reached, and 60% of the cuttings were granitic chips. At 6:00 pm, the depth was 2485.3 m (8154 ft) with 95% granitic chips in the cuttings. The load was increased gradually to 5.4 Mg (12 000 lb), and the penetration rate increased to 3 - 4 m/h (10 - 12 ft/h), with the amount of cement in the cuttings decreasing to virtually zero.

Hole GT-2A was considered to be sidetracked at a depth of 2482.3 m (8144 ft). Pumping into EE-1 to pressurize the fracture zone began at a rate of 130 liters/m (34 gpm).

Drilling ahead continued until the bit began to run rough and was pulled from the hole. The depth was 2503.9 m (8215 ft); maximum penetration rate had been 3.7 m/h (12 ft/h) at a load of 5.4 Mg (12 000 lb). The bit had drilled 22 m (71 ft) in 10-3/4 h; it had three cracked and chipped buttons and was 0.3 cm (1/8 in.) out of gauge.

A rerun 24.5-cm (9-5/8-in.) Smith 9JA bit with single reamer and Monel collar was run in to continue drilling. This bit was pulled after drilling to 2547.2 m (8357 ft). The orientation at that depth was N39°E with a deviation of 6° from vertical. The reamers and bit were 0.15 cm (1/16 in.) undergauge.

Drilling ahead then progressed with a new 24.5-cm (9-5/8-in.) Smith 9JA bit at a penetration rate of 2 - 3 m/h (7 - 10 ft/h). An orientation taken on May 4 at a depth of 2587.8 m (8490 ft) gave a direction of N25°E with a deviation of 9.25° from the vertical. The bit was pulled from the hole at a depth of 2589.6 m (8496 ft), and a stiffer drilling assembly consisting of a new Smith 24.5-cm (9-5/8-in.) button bit, a three-point reamer, a short collar, and another three-point reamer was made up to decrease the angle of deviation. This assembly was used to drill to 2662.7 m (8736 ft).

At 10:30 pm at 2635.0 m (8645 ft), the pressure in EE-1 began to drop about 3.4 Pa/min (0.5 psi/min). This depth was the calculated location of the top of the fracture zone if the fracture was vertical. Drilling with a new bit continued to a depth of 2799.3 m (9184 ft), for a single bit run of 136.6 m (448 ft) in 52 h. The flow from EE-1 to GT-2 varied from 26.5 to 34.1 liters/m (7 to 9 gpm).

A coring run was made on May 9 at this depth with a Christensen 24.5-cm-o.d. by 11.4-cm-i.d. (9-5/8-in.-o.d. by 4-1/2-in.-i.d.) diamond bit, but no core was obtained.

On May 11 and 12, high-temperature Lynes packers were set successively at depths of 2522.2 m (8275 ft) and 2513.1 m (8245 ft) in GT-2A to pressurize the hole to improve the connection. The drilling rig was put on standby status until May 17 while pressurization experiments and temperature logs were run.

The tests indicated that the impedance to flow between the two holes was still too high for a meaningful circulation experiment. Accordingly, plans were made to redrill to intersect the fracture zone at a lower elevation.

3. Hole GT-2B. The plan for the second redrill consisted of sidetracking out of Hole GT-2A at 2529.8 m (8300 ft) to intersect the fracture at about 2682.2 m (8800 ft). On May 18, a cement plug (110 sacks of Class B cement, 40% silica flour, no coloring agent) was set through open-ended drill pipe at a depth of 2571.6 m (8437 ft).

Drilling began with a Smith 24.5-cm (9-5/8-in.) 9JA bit on a drill collar with a stabilizer above. The top of the cement was encountered at 2479.6 m (8135 ft). At 2510.3 m (8236 ft), it appeared as though the bit was just scraping along the side of the hole and not cutting a ledge, so the assembly was pulled.

A 20.0-cm (7-7/8-in.) Smith 9JS button bit with a Dyna-Drill and 2° bent sub was run in the hole, oriented and rotated slowly up and down several times from 2509.7 to 2510.9 m (8234 to 8238 ft) in an attempt to find an irregularity in the sidewall to drill on. When this proved unsuccessful, drilling ahead on the cement plug continued at a rate of 0.3 m/h (1 ft/h). After 6 h, a depth of 2513.7 m (8247 ft) had been reached with a load of 1.4 Mg (3000 lb) being gradually built up. Two hours later, at 2517.9 m (8261 ft), a load of 2.3 Mg (5000 lb) had been attained. When the bit was pulled from that depth, it was 0.6 cm (1/4 in.) under gauge and showed severe wear on the outside buttons, but very little on the inside buttons.

When a 24.5-cm (9-5/8-in.) Smith button bit was run down the hole on the same Dyna-Drill assembly, the shoulder cut by the 20.0-cm (7-7/8-in.) bit could not be located. Drilling progressed to 2520.4 m (8269 ft) without any appreciable load; the string was then pulled and a new Smith 24.5-cm (9-5/8-in.) 9JA bit installed and run in with the Dyna-Drill. After five orientation surveys, drilling began at 3:00 pm on Saturday, May 21. Drilling ahead progressed slowly at a rate of 0.3 m/h (1 ft/h) and a load of 0.9 Mg (2000 lb). The penetration rate was gradually increased to 1 m/h (3 ft/h) as the load increased to 1.4 Mg (3000 lb). By 7:00 am on May 22, the depth was 2529.8 m (8300 ft) with a load of 4.1 Mg (9000 lb). Drilling continued to 2534.1 m (8314 ft), then the assembly was

pulled. The bit was well worn across the cones and about 0.3 cm (1/8 in.) out of gauge.

A new Smith 24.5-cm (9-5/8-in.) 9JA bit and reamer assembly was made up (no Dyna-Drill) and run in for drilling ahead. A survey at 2:30 am on May 23, at a depth of 2554.2 m (8380 ft), indicated a deviation of 3° and a direction of N6°E. By 7:30 am, the depth was 2564.9 m (8415 ft), drilling at a rate of 2.7 m/h (9 ft/h) and a load of 18.1 Mg (40 000 lb) with the cuttings nearly all granitic chips.

Hole GT-2B was considered to be sidetracked at a depth of 2520.7 m (8270 ft). Drilling continued to a depth of 2610.6 m (8565 ft), when a new Smith 9JA bit was run in on a Dyna-Drill assembly. Pumping into EE-1 at a rate of 130 liters/m (34 gpm) to inflate the fracture system also began at this time. At 2647.5 m (8686 ft), the assembly was pulled and the same Smith 9JA bit was run in on a six-point reamer to ream the hole to bottom. A downhole survey indicated a direction of N77°E and a deviation of 5.25° from the vertical, which was a more easterly direction than desired.

The Electronic Yaw Equipment (EYE) device of Scientific Drilling Controls, Newport Beach, California, was run downhole on May 26 to give closer control of the drilling direction. After a day spent in getting the EYE tool to operate in the downhole environment, we found that the Dyna-Drill could not be oriented properly because of the extreme curvature of the hole. A conventional assembly with a Smith 9JA bit was used to drill the next 9.1 m (30 ft) of hole before continuing directional drilling.

At 7:30 pm on May 28, drilling with the Dyna-Drill and EYE began at 2656.6 m (8716 ft). At 10:05 pm, a sharp pressure decrease in EE-1 was noted, at a depth of 2672.8 m (8769 ft). Drilling was halted immediately according to a prearranged plan; the hole was surveyed and the drill string pulled from the hole.

On May 29, a Christensen 21.6-cm-o.d. by 11.4-cm-i.d. (8-1/2-in.-o.d. by 4-1/2-in.-i.d.) diamond core bit was run in. Coring began at 1:15 pm and continued until 11:00 pm. After drilling 1.2 m (4 ft) to a depth of 2674.0 m (8773 ft), the bit stopped cutting and was pulled. Four pieces of core, with a reconstructed length of 63.5 cm (25 in.), were recovered.

The following day, the Dyna-Drill assembly with the EYE was run in, but troubles with both tools prevented any further drilling. An 8-h pumping test was conducted to determine the impedance of the EE-1/GT-2 connection. The hole was then reamed to bottom and an additional 1.5 m (5 ft) drilled to a depth of 2675.5 m

(8778 ft). Subsequent temperature logs indicated a well-defined flow of water entering GT-2B at about 2673.1 m (8770 ft) and a lesser flow at a higher elevation.

A Lynes high-temperature packer was set in GT-2B at 2653.6 m (8706 ft) for a pressurization and refracturing experiment. After the packer was pulled, the drilling rig was put on standby status until June 8, while more circulation tests were conducted. Pumping into EE-1 continued for 20 h at 380 liters/m (100 gpm) and 6.9 MPa (1000 psi). At the culmination of the test, the outlet temperature at GT-2 was 130°C (266°F) (Fig. 15).

Drilling began again on June 8 with a conventional assembly and continued to 2710.6 m (8893 ft). A coring run to 2712.1 m (8898 ft) with a Christensen 21.6-cm-o.d. by 11.4-cm-i.d. (8-1/2-in.-o.d. by 4-1/2-in.-i.d.) diamond core bit produced no core. An additional foot of hole was drilled with a conventional assembly to ream and clean the hole, and a series of logging tests was conducted over

Fig. 14.
Underreamer assembly used to enlarge
hole to 40.6 cm (16 in.).

Fig. 15.
Steam flow from GT-2 on June 3, 1977,
Experiment No. 166.

the next 5 days. On June 14, the hole was cleaned and reamed to bottom, and another coring attempt was made with a Christensen 24.5-cm-o.d. by 14.0-cm-i.d. (9-5/8-in.-o.d. by 5-1/2-in.-i.d.) diamond bit. The coring assembly could not get closer than 12.8 m (42 ft) to bottom, so the run was aborted.

Another coring attempt was made on June 18 (Fig. 16), with a Christensen 21.6-cm-o.d. by 14.0-cm-i.d. (8-1/2-in.-o.d. by 5-1/2-in.-i.d.) diamond bit to a depth of 2713.3 m (8902 ft), but no core was recovered.

A newly developed Smith Tool Company 20.0-cm-o.d. by 11.4-cm-i.d. (7-7/8-in.-o.d. by 4-1/2-in.-i.d.) combination Stratopax and chisel tooth, tungsten carbide insert, roller cone core bit was next used. Drilling progressed at 0.6 m/h (2 ft/h) to 2714.9 m (8907 ft). About 136 cm (53.5 in.) of core were recovered. Drilling in GT-2B was terminated at that depth.

4. Hole Completion. The hole was completed in the following manner.

(a) A cement plug was set above the intersection between GT-2B and the fracture at 2636.5 m (8650 ft). The plug was faced off at 2612.8 m (8572 ft).

(b) 19.4-cm-o.d. (7-5/8-in.) casing was set from the plug to the surface (Figs. 17 and 18).

(c) The bottom 457.2 m (1500 ft) of casing was cemented, and the Noble drilling rig was released on June 24.

(d) A truck-mounted pulling rig, DA&S Oil Well Servicing Company of Hobbs, New Mexico, was used to drill out the cement in the casing and through the cement plug (Fig. 19).

(e) A magnet run was made to bottom to clean the hole.

(f) Hydraulic jacks were positioned at the wellhead and the casing was set with a final tensile load of 186 Mg (410 000 lb).

(g) The pulling rig was released on July 10.

A composite plan view of the bottom section of EE-1 and GT-2 is shown in Fig. 20, with GT-2A and GT-2B noted. The EE-1/GT-2 downhole connection is shown in elevation view in Fig. 21.

VI. CASING

During the early planning for the redrilling of GT-2, the hole was scheduled to be cased with 21.9-cm (8-5/8-in.) buttress-thread N-80 casing. The maximum size of hole that could be drilled was 24.5 cm (9-5/8 in.), because of the 27.3-cm (10-3/4-in.) casing previously placed to a depth of 772.7 m (2535 ft).⁵ Because

Fig. 16.
Diamond core bit and coring assembly
before running in hole on June 18.

Fig. 17.
Drawing 19.4-cm-o.d. (7-5/8-in.-o.d.)
casing up to drilling floor.

Fig. 18.
Installing 19.4-cm-o.d. (7-5/8-in.-o.d.)
casing.

Fig. 19.
Workover rig, drilling out the cement
plug at GT-2.

Fig. 20.

Plan view bottom section of EE-1 and GT-2, showing paths of GT-2A and GT-2B.

Fig. 21.

Elevation view of the EE-1/GT-2 down-hole connection.

21.9-cm (8-5/8-in.) casing had been placed in EE-1, no particular trouble was anticipated in placing similar-sized casing in GT-2B.

However, the commercial cementing consultant strongly advised against using 21.9-cm (8-5/8-in.) casing in GT-2B for three reasons:

- The extreme curvature of the hole at the GT-2B kick-off point might prevent the casing from being run to bottom.
- The small annulus (almost zero at the casing collars) might result in a low-quality cementing operation.
- Future plans might require pulling the casing for continued drilling, and the larger casing size would make wash-over and removal extremely expensive, if not impossible.

Accordingly, 19.4-cm (7-5/8-in.) casing was procured. The first string of this size that arrived at Fenton Hill was rejected because of flaws detected by a Magnaflux inspection; the second string was received and accepted in time to prevent any delay in the program.

On June 24, the 19.4-cm (7-5/8-in.) casing string was run downhole to touch the top of the cement plug at a depth of 2612.8 m (8572 ft), and then was pulled up 0.7 m (2 ft). A 80-m³ (500 bbl) solution containing 1.1 m³ (275 gal) of Baroid Coat B-1400 passivation fluid was pumped into the annulus before cementing began. The string consisted of 798.5 m (2619.7 ft) of 50.2-kg/m (33.7-lb/ft) Grade S-95 casing placed on bottom, followed by 853.3 m (2799.7 ft) of 50.2-kg/m (33.7-lb/ft) Grade N-80 casing, with 962.6 m (3158 ft) of 50.2-kg/m (33.7-lb/ft) Grade S-95 casing at the top of the hole (all Range III). A Halliburton float shoe was installed on the bottom of the string with a Halliburton float collar inserted one joint up. Twenty-two centralizers were spaced along the bottom 20 joints. The S-95 casing was placed at the bottom, where compressive stresses would be the greatest, and again at the top to accommodate the greater tensile stresses.

Halliburton Oil Well Cementing Company began cementing at 6:00 am on June 24, immediately after the passivation fluid was emplaced. A total of 15.35 Mg (360 sacks) of Class B cement, with 40% silica flour (20% fine, 20% coarse), 1.5% HR-12 and 0.75% CFR-2, was pumped in and displaced with 60.5 m³ (380 bbl) of water. The fill-up was calculated to be 730 m (2395 ft) for a 25.4-cm (10-in.) hole.

The cement plug bumped solidly on bottom with a pressure of 6.9 MPa (1000 psi); the pressure built up to 12.1 MPa (1750 psi), was held for 5 min, and then released.

The weight of the casing string by the rig weight indicator was 114.3 Mg (252 000 lb). A weight of 90.7 Mg (200 000 lb) was supported by the casing slips while the cement hardened.

After the float shoe and cement plug were drilled out, hydraulic casing jacks were placed over the hole and the casing was set with a tensile load of 186 Mg (410 000 lb) on the load cells.

VII. DRILLING MEDIA

Although plain water was used in most of the drilling operations, a drilling mud mixture of Baroid Quikgel was used occasionally to clean the hole. After the Dyna-Drill assembly was plugged with cement cuttings on the first directional drilling run, 190 sacks of Quikgel and 12 sacks of soda ash were mixed in the mud tanks and circulated as an aid in lifting the cuttings out of the hole. Thereafter, a mixture of Quikgel became standard practice for cleaning and circulating

the hole at the end of each drilling run and before coring and logging. A weight of about 1 kg/liter (8.3 - 8.5 lb/gal) with a viscosity of 29 - 31 s* was initially maintained. As the depth progressed, the fluid weight increased to 1 kg/liter (8.4 - 8.6 lb/gal).

On May 2, at a depth of 2560 m (8400 ft) in GT-2A, a pilot test was conducted to lower the high-temperature gelation of the mud mixture by adding small amounts of Baroid Desco and Carbonox. The test was inconclusive and the practice was never adopted.

VIII. CEMENTING

Cementing operations in the GT-2 redrilling program fall into three categories:

- Cement plugs for sidetracking
- Cement plug before setting casing
- Cementing casing.

All cementing work was performed by Halliburton Cementing Services of Farmington, New Mexico. The basic mix design, accepted as the high-strength, chemical- and heat-resistant mix standard throughout the oil industry, was used in all operations. This mix consisted of Class B cement, 40% silica flour, plus proprietary additives of retardants and friction reducers. A summary of the operations is given in Table I. All cement was placed through open-ended drill pipe except for the cementing of the casing.

IX. DRILL BIT PERFORMANCE

A. Chisel-Tooth

The only toothed bit used during the redrilling operation was a Security 25.1-cm (9-7/8-in.) H7SGT bit, during the third and fourth Dyna-Drill run of the first sidetracking attempt. The two previous runs were conducted with button bits, but as sidetracking was not accomplished we thought that a toothed bit might perform better. Drilling with the bit began at 2488.1 m (8163 ft), (after rotating it on bottom for 15 min) at a controlled penetration rate of 0.3 m/h (1 ft/h) with a weight of 1.4 Mg (3000 lb). At 2491.1 m (8173 ft), drilling was halted and the bit rotated for 1.5 h. Drilling then began again at a penetration

*American Petroleum Institute funnel viscosity.

TABLE I
SUMMARY OF CEMENTING OPERATIONS

Date	Amount		Remarks
	Mg	Sacks	
April 6	5.33	125	Plug for sidetracking, pipe at 2580.1 m (8465 ft). Cement not hard enough.
April 10	5.33	125	Plug for sidetracking, pipe at 2529.8 m (8300 ft). Less water and retarder used in mix.
April 23	6.40	150	Plug for sidetracking after underreaming hole to 40.6-cm (16-in.), pipe at 2450.6 m (8040 ft). Hole successfully sidetracked at 2482.3 m (8144 ft).
May 18	4.69	110	Plug for second sidetracking, pipe at 2571.6 m (8437 ft) in GT-2A. Hole successfully sidetracked at 2520.7 m (8270 ft).
June 20	2.13	50	Plug before setting casing, pipe at 2636.5 m (8650 ft). Plug moved up the hole about 150 m (500 ft); no solid cement encountered. Cement probably dispersed by flow from EE-1.
June 21	2.13	50	Same operation as previous day, but with EE-1 shut in and unpressurized. Top of hard plug at 2595.4 m (8515 ft), drilled out to 2612.8 m (8572 ft).
June 23	15.35	360	19.4-cm (7-5/8-in.) casing set at 2612.1 m (8570 ft). Maximum fill-up calculated to be 730 m (2395 ft) for a 30.5-cm (10-in.) hole. Cement plug bumped on bottom with a pressure of 6.9 MPa (1000 psi); pressure built to 12.1 MPa (1750 psi), was held for 5 min, then released. Drilling of cement shoe completed on July 7.

rate of 0.6 m/h (2 ft/h) with a weight of 2.7 Mg (6000 lb). At 2494.2 m (8183 ft), it appeared that sidetracking had not been accomplished, because the weight had not increased or the penetration rate decreased, so the bit was pulled. Examination showed evidence of extreme wear on the outer edges of the outside row of teeth and gauge buttons, as if it had been trying to cut into the side of the hole (Fig. 11).

B. Diamond

Ten bit runs were made with diamond full-face bits. All of these runs were involved in the sidetracking operation of Hole GT-2A. Experience had indicated that the life of diamond bits in cutting granitic rock was very short, and the sidetracking efforts confirmed this. However, because diamond bits were the only

tools available with any side-cutting capability, they were used extensively. A good working relationship was established with Christensen Diamond Products of Salt Lake City, Utah, in an effort to increase penetration and sidetracking rates. When a diamond bit was pulled from the hole, a description of the wear pattern on the diamonds was telephoned to Christensen, and an improved mold was made that night, a new bit blank was cast, diamond placed, and the completed bit was air freighted to Los Alamos the following day.

In spite of this constant design improvement, the maximum diamond bit life in granitic rock was only 1 m (3 ft), between 2481.4 and 2482.4 m (8141 and 8144 ft). This run culminated in the sidetrack of GT-2A. Although many of the diamond bits lasted longer (as seen on the bit record in Appendix E and Dyna-Drill summary, Table II), they did not actually cut the granitic rock. Most of these runs consisted of drilling the softer cement plug material. One of the major problems in using the diamond side-cutting bits was that the gauge diamonds apparently were completely worn off going downhole on the bent sub/Dyna-Drill assembly.

C. Button

Smith tricone 9J button bits were used exclusively during the sidetracking of GT-2B. A 20-cm (7-7/8-in.) 9JS bit was used during the second run in an attempt to make a pilot hole, but the shoulder cut by the bit (if there was one) could not be located on the subsequent run. Two bit runs later, the hole was successfully sidetracked.

The bits performed well, but most were withdrawn from the hole before failure, because of the need to change the bottom-hole drilling assembly or the Dyna-Drill. During the drilling of the lower part of GT-2A, a 9JA 24.5-cm (9-5/8-in.) bit was run to failure. It drilled a total of 136.6 m (448 ft) in 52 h, at a rotary speed of 40 rpm and a weight of 22.7 Mg (50 000 lb).

Because of the high rotational speed of the Dyna-Drill motor, and the short runs, little meaningful wear information can be extracted from the data.

X. CORING

A. Diamond

Five coring attempts were made with diamond bits, but only the run on May 29 produced any core. Examination of the diamond core bits during the May 9 and June 15 runs showed the diamonds on the outside of the bit to be completely worn away. This may have resulted from "taper jam" — the bottom of the hole being

under gauge from not being reamed (May 9), or being reamed with a slightly under-gauge bit (June 15), or a result of the hole curvature.

The wear pattern of the bits retrieved from the June 9 and 18 runs showed extreme wear on the cutting surface, with all trace of the diamonds gone. The Christensen drilling engineer believed that this condition was caused by pieces of loose rock rolling around underneath the bit, with no core being cut. On both these runs the 21.6-cm (8-1/2-in.) size allowed the bit to get easily to bottom. Before the June 9 run, two pills, each consisting of 7 sacks Baroid Quikgel and 1-1/2 sacks Cellex, were circulated to remove the cuttings. The average penetration rate on the June 9 run was 0.3 m/h (1 ft/h), and 0.1 m/h (0.4 ft/h) on the June 18 run. In both attempts, the initial rotational speed was about 30 rpm and the final was 50 rpm; the load increased from 6.8 Mg (15 000 lb) to 15.9 Mg (35 000 lb).

In the successful coring run of May 29, the immediately previous drilling consisted of 9 m (30 ft) of straight hole with a 9JA 24.5-cm (9-5/8-in.) button bit and six-point reamer. The coring bit was 21.6-cm (8-1/4-in.), but some slight difficulty was experienced in the last 12 m (40 ft) to bottom. Coring began at a rotational speed of 40 rpm and a load of 13.6 - 15.9 Mg (30 000 - 35 000 lb). The average penetration rate was 0.1 m/h (0.4 ft/h); the rotational speed and load was gradually increased to 60 rpm and 20.4 Mg (45 000 lb). A summary of the coring operations is shown in Table III.

B. Stratopax

The last coring run, on June 19 from 2713.3 to 2714.9 m (8902 to 8907 ft), was done with a newly developed Smith Tool Company combination Stratopax and chisel-tooth, tungsten carbide insert, roller cone bit (Fig. 22a). Because this was the very first field test of this new bit, the chief designer from Smith Tool in Irvine, California, and an American Coldset Corporation representative from Joaquin, Texas, were at the site on June 18 to supervise the coring operation. A summary of this coring operation is also given in Table III.

The coring assembly consisted of a six point, 1-m- (3-ft-) long stabilizer immediately above the bit, followed by an 8.2-m- (27-ft-) long core barrel, a five-point 1.6-m- (5.4-ft-) long stabilizer, and a three-point reamer assembly. Coring began at a rotational speed of 32 rpm and a load of 6.8 Mg (15 000 lb). The rotational speed was gradually increased to 48 rpm; and the rotational torque nearly doubled. Penetration rate averaged 0.6 m/h (2 ft/h). Examination after

the bit was pulled showed three of the four studs broken off (Fig. 22b). The cones were loose and the chisel teeth were worn almost smooth. From the 1.5-m (5-ft) run, about 152 cm (53.5 in.) of broken cone was recovered.

(a)

(b)

Fig. 22.

Combination Stratopax and chisel-tooth roller cone bit (a) before drilling and (b) after drilling. Three of the four studs were broken off, and the Stratopax facing was worn off the remaining stud.

TABLE II

SUMMARY OF DYNA-DRILL OPERATIONS - HOLE GT-2A

Dyna-Drill Number	Bent Sub	Date of Run	Depth [m (ft)]	Operating Time (h)		Bit	Remarks
				In Hole	On Bottom		
76327 ^a	2°	4/9/77	2518.6 (8263)	16	4	Sm ^b 24.5 cm (9-5/8 in.) 9JA button	Dyna-Drill (DD) did not operate, tool plugged with fill, stator overheated and damaged, sent to Midland, Texas, for repair.
76197	2°	4/9/77	2518.6-2543.0 (8263-8343)	21	10	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfactorily; partial disintegration of rubber marine bearing seal, sent for repair. Unable to side-track, recementing required.
65672 1-1/2° bent housing	1-1/2°	4/12/77	2488.1 (8163)	10	1	Sec ^c 25.1 cm (9-7/8 in.) H7SGJ tooth	Drill collars plugged with cement cuttings. DD did not operate.
Same	1-1/2°	4/13/77	2488.1-2494.2 (8163-8183)	13	9	Sec 25.1 cm (9-7/8 in.) H7SGJ tooth	DD operated satisfactorily.
Same	1-1/2°	4/14-15/77	2494.2-2498.8 (8183-8198)	17	8	Ch ^d 25.1 cm (9-7/8 in.) MD-411ST dia. ^e	DD operated satisfactorily, partial disintegration of rubber marine bearing seal, sent for repair.

^aDyna-Drill numbers, 76XXX denotes 19.7-cm (7-3/4-in.) diam; 65XXX denotes 16.5-cm (6-1/2-in.) diam

^bSm - Smith Tool Company

^cSec - Security Dresser Industries

^dCh - Christensen Diamond Products Company

^edia. - diamond bit

TABLE II (cont)

SUMMARY OF DYNA-DRILL OPERATIONS - HOLE GT-2A

Dyna-Drill Number	Bent Sub	Date of Run	Depth [m (ft)]	Operating Time (h)		Bit	Remarks
				In Hole	On Bottom		
76291	1-1/2°	4/16/77	2505.5 (8220)	10	1	Ch 24.5 cm (9-5/8 in.) MD-43ST dia.	DD did not operate, wire- line broke, pulled tool.
Same	2°	4/17/77	2505.5-2508.2 (8220-8229)	19	11	Ch 24.5 cm (9-5/8 in.) MD-43ST dia.	DD operated satisfac- torily.
Same	2°	4/18/77	2508.2-2509.4 (8229-8233)	16	8	Ch 24.5 cm (9-5/8 in.) MD-43ST dia.	Rubber marine bearing seal deteriorated, sent for repair.
76327	2°	4/19/77	2509.4-2513.4 (8233-8246)	15	7	Ch 24.5 cm (9-5/8 in.) MD-41ST dia.	Rubber marine bearing seal deteriorated, sent for repair.
76197	2°	4/20-21/77	2515.2-2518.3 (8252-8262)	16	9	Ch 24.5 cm (9-5/8 in.) MD-331 dia.	DD operated satisfac- torily, sent for over- haul. Unable to side- track after conventional drilling run to 2523.7 m (8280 ft). Underreaming and recementing required.
65661	2°	4/25-26/77	2471.9-2476.8 (8110-8126)	20	9	Ch 20 cm (7-7/8 in.) MD-43GST dia.	DD operated satisfac- torily. DD assembly contained fiber glass marine bearing seal.
Same	2°	4/26/77	2476.8-2481.1 (8126-8140)	19	10	Ch 20 cm (7-7/8 in.) MD-43GST dia.	DD operated satisfac- torily.
Same	2°	4/27/77	2476.8-2480.8 (8126-8139)	15	4	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfac- torily; reamed hole.

TABLE II (cont)

SUMMARY OF DYNA-DRILL OPERATIONS - HOLE GT-2A

Dyna-Drill Number	Bent Sub	Date of Run	Depth [m (ft)]	Operating Time (h)		Bit	Remarks
				In Hole	On Bottom		
76327	2°	4/29/77	2480.8-2481.1 (8139-8140)	11	3	Ch 24.5 cm (9-5/8 in.) MD-43GST dia.	DD operated satisfactorily, bit did not cut, loose rock in bottom of hole.
Same	2°	4/29/77	2481.1-2481.4 (8140-8141)	19	2	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfactorily, clean-up run. DD assembly kept at site.
76291	2°	4/29/77	2481.4-2482.3 (8141-8144)	14	5	Ch 24.5 cm (9-5/8 in.) MD-43GST dia.	DD operated satisfactorily, bit quit cutting.
Same	2°	4/30/77 5/1/77	2482.3-2503.9 (8144-8215)	19	11	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfactorily, no apparent damage to DD assembly. Hole GT-2A considered sidetracked at 2482.3 m (8144 ft).

SUMMARY OF DYNA-DRILL OPERATIONS - HOLE GT-2B

65648	2°	5/19/77	2510.9-2518.0 (8238-8361)	22	14	Sm 20 cm (7-7/8 in.) 9JS button	DD operated satisfactorily, unable to sidetrack.
Same	2°	5/20/77	2510.9-2520.4 (8238-8269)	21	13	Sm 24.5 cm (9-5/8 in.) 9JA button	Reamed hole and continued drilling; unable to sidetrack, could not locate shoulder of 20-cm (7-7/8 in.) hole.
Same	2°	5/21/77	2520.4-2534.1 (8269-8314)	23	14	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfactorily, Hole GT-2B considered sidetracked at 2520.7 m (8270 ft).

TABLE II (cont)

SUMMARY OF DYNA-DRILL OPERATIONS - HOLE GT-2B

Dyna-Drill Number	Bent Sub	Date of Run	Depth [m (ft)]	Operating Time (h)		Bit	Remarks
				In Hole	On Bottom		
65670	2°	5/24-25/77	2610.6-2647.5 (8565-8686)	24	17	Sm 24.5 cm (9-5/8 in.) 9JA button	DD operated satisfactorily but difficult to hold direction. Ordered Scientific Drilling Control "EYE" to site.
65686	2°	5/26/77	2647.5 (8686)	8	1	Sm 24.5 cm (9-5/8 in.) 9JA button	SDC "EYE" did not work, pulled DD tool without operating.
Same	2°	5/27/77	2647.5 (8686)	27	19	Sm 24.5 cm (9-5/8 in.) 9JA button	Could not orient DD assembly correctly because of extreme curvature of hole. Pulled DD tool without operating.
65670	2°	5/28/77	2656.6-2672.8 (8716-8769)	16	6	Sm 24.5 cm (9-5/8 in.) 9JA button	Drilled 9 m (30 ft) of straight hole with conventional assembly, then continued with DD assembly and SDC "EYE". Fracture intersected at 2672.8 m (8769 ft); tool pulled.
65661	2°	5/30/77	2675.5 (8778)	9	1	Sm 24.5 cm (9-5/8 in.) 9JA button	DD tool would not turn on bottom, operated OK upon withdrawal. May have been plugged with cuttings, but washed out on way out of hole.
65670	2°	5/30-31/77	2675.5 (8778)	8	1	Sm 24.5 cm (9-5/8 in.) 9JA button	DD tool would not turn on bottom, possibly plugged. Terminated directional drilling.

TABLE III
SUMMARY OF CORING OPERATIONS

Date (1977)	Cored Interval Depth [m (ft)]	Recovery (%)	Core Bit	Remarks
May 9	2799.3 (9184) GT-2A	0	Ch ^a 24.5-cm o.d. by 11.4-cm i.d. (9-5/8 by 4-1/2 in.)	Junk basket run first, but no reaming bit run. Experienced difficulty getting past kick-off point at 2482.3 m (8144 ft). Reamed to bottom with coring bit; bit badly worn on outside surfaces. Probably no core cut.
May 29	2672.8-2674.0 (8769-8773) GT-2B	52	Ch 21.6-cm o.d. by 11.4-cm i.d. (8-1/2 by 4-1/2 in.)	Biotite Granodiorite. Previous drilling was 9 m (30 ft) of straight hole cut with Smith 24.5-cm (9-5/8-in.) 9JA button bit; hit fracture zone at 2672.8 m (8769 ft). Core showed three fracture planes, two still sealed with calcite and one reopened.
June 9	2710.9-2712.1 (8894-8898) GT-2B	0	Ch 21.6-cm o.d. by 11.4-cm i.d. (8-1/2 by 4-1/2 in.)	Previous 18.3 m (60 ft) reamed with rerun 24.5-cm (9-5/8-in.) 9JA button bit, plus 4.6 m (15 ft) new hole. Supposedly cored 1.2 m (4 ft) in 4 h. Core bit showed extreme wear on cutting surface, deep into matrix metal. Drilling engineer's opinion: loose pieces of rock rolling around under bit and no core cut.
June 15	2712.7 (8900) GT-2B	0	Ch 24.5-cm o.d. by 14.0-cm i.d. (9-5/8 by 5-1/2 in.)	Reamed hole to bottom with new 24.5-cm (9-5/8-in.) button bit and junk basket. Could only get core bit down to 12.8 m (42 ft) of bottom. Outside diamonds of core bit completely worn off.
June 18	2712.7-2713.3 (8900-8902) GT-2B	0	Ch 21.6-cm o.d. by 14.0-cm i.d. (8-1/2 by 5-1/2 in.)	Core bit was worn in same pattern as June 9; same opinion.

^aCh - Christensen Diamond Products Company bit.

TABLE III (cont)
SUMMARY OF CORING OPERATIONS

Date (1977)	Cored Interval Depth [m (ft)]	Recovery (%)	Core Bit	Remarks
June 19	2713.3-2714.9 (8902-8907) GT-2B	89	Sm ^b 20.0-cm o.d. by 11.4-cm i.d. (7-7/8 by 4-1/2 in.)	Biotite Granodiorite. Penetration rate 0.6 m/h (2 ft/h). Bit was retrieved with three studs broken off and chisel teeth worn smooth. Core contained several distinct fracture surfaces, with possible evidence of pumping flow.

^bSm - Smith Tool Company combination Stratopax and chisel-tooth, tungsten carbide insert, roller cone core bit.

XI. DIRECTIONAL DRILLING

All directional drilling was done with Dyna-Drill tools, and these assemblies generally worked well. The only instance of major damage done to any of the Dyna-Drill tools occurred on the first run on April 9. The tool became plugged with cement cuttings before it operated, and the stator was torn. The life of each individual tool was relatively short at the start of the redrilling program, because of partial disintegration of the radial, rubber marine bearing seals at the lower end of the tool. After April 23, a new type of fiberglass seal (Duralon) was used which gave a better performance at elevated temperatures.

Once a Dyna-Drill was broken in, it was used as long as practical. As the tool became worn, the "loose" fit of the internal parts allowed more cooling water to circulate, thus increasing its efficiency in the hot environment. When the directional drilling supervisor decided that the tool had been run long enough, it was sent to Midland, Texas, for overhaul.

A summary of the Dyna-Drill operations is shown in Table II. Static hole temperatures (ambient rock) averaged 172°C (342°F) for the GT-2A redrilling; rock temperatures in GT-2B ranged from 172 - 180°C (342 - 356°F) at a depth of 2672.8 m (8769 ft).

Two important changes were made in the directional drilling sidetracking attempts of GT-2A and 2B. The deviation in GT-2B was purposefully made (1) from the low side of the existing GT-2A borehole, and (2) from a selected portion of the hole that was believed to have a ledge in it. The GT-2B sidetracking effort was accomplished in 2-1/2 days with button bits, whereas the GT-2A attempt required 2-1/2 wk and many diamond bits.

XII. PACKERS

A. Field Use

A description of the packer procurement schedule, size, and evaluation testing is included in Sec. V.A.4. During field use, all the packers were set with a retrievable Otis standing valve on a wireline, at a setting pressure of 10.3 MPa (1500 psi).

On May 11, after the fracture zone originating from EE-1 had been intersected at 2635.8 m (8645 ft) by the first sidetracked (GT-2A) bore, a high-temperature packer was used in an attempt to improve the connection between the holes. The packer was set at 2522.2 m (8275 ft) in GT-2A. Pumping into GT-2 began at a

rate of 10.6 liters/s (4 bbl/min) at 10.7 MPa (1550 psi). A water flow up the annulus occurred a short time later; at that time we assumed that the packer was leaking, and therefore discontinued pumping. When the packer was pulled, the rubber cover had been completely stripped off.

The next day, a second packer was set at 2513.1 m (8245 ft) in GT-2A, and the hole was pressurized to 11 MPa (1600 psi) at a flow rate of 2.6 liters/s (1 bbl/min). In about 20 min, flow again occurred up the annulus. A check of the load on the packer indicated that it was apparently still holding. Pumping was increased to 23 liters/s (5-1/2 bbl/min), the pressure rose to 12.6 MPa (1830 psi), while the annulus flow increased to 4.7 liters/s (75 gpm). After 160 m³ (1000 bbl) had been injected, pumping was terminated and the hole shut in. When the packer was pulled, all of the rubber cover was again missing.

On May 27, a second intersection of the EE-1 fracture zone was accomplished with the second sidetracked bore (GT-2B) at a depth of 2672.8 m (8769 ft). A third packer assembly was made up and was set at 2653.6 m (8706 ft) on June 1 to determine the amount of impedance between the two holes. Pumping began at a rate of 2.6 liters/s (1 bbl/min) and was increased to 13 liters/s (5 bbl/min) with a pump pressure of 12.6 MPa (1830 psi). The packer held well, with only a small annulus leak developing after several hours of pumping. When this packer was pulled, the rubber cover sheath remained in the hole, as shown in Fig. 23. Remains of the rubber element continued to be circulated out of the hole on the last day of drilling, July 8, but presented no problems.

B. Conclusions

The Lynes high-temperature inflatable formation packers performed satisfactorily at the elevated downhole temperature of 180°C (360°F). The observed leakage into the annulus probably occurred through fractures in the rock around the packer. No attempt was made to set two elements in series which might have reduced such bypass leakage.

XIII. LOGGING

A. Phase IV

Geophysical logging operations during the Phase IV predrilling operations are described in Sec. III and Appendix A. As a result of the cement-bond log (Fig. 24) and radioactive iodine tracer experiments in EE-1 on February 7-11 by Dresser Atlas (Experiment 156), we determined that little or no cement existed

behind the casing from 2926 to 2749 m (9600 to 9020 ft). This bond log also indicated an average of 30 - 95% bonding from 2749 to 2500 m (9020 to 8200 ft), with 3- to 6-m (10- to 20-ft) sections of no bond occurring at depths of about 2737, 2722, and 2702 m (8980, 8930, and 8865 ft).

Immediately after cementing operations on October 27, 1975, the cement-bond log by Dresser Atlas indicated a 30 - 50% bond from 2926 to 2749 m (9600 to 9020 ft) and a 95 - 98% bond from 2749 to 2408 m (9020 to 7900 ft).¹²

As determined by the iodine tracer experiment, water pumped into EE-1 flows from the bottom of the casing up the open annulus into a fracture at about 2743 m (9000 ft) and then into GT-2.

B. Phase V

1. EE-1 Logging. On July 11, 1977, Dresser Atlas ran cement-bond logs in GT-2B and EE-1 (Fig. 24). This latest log in EE-1 showed evidence of extension and enlargement of the unbonded section that was noted behind the casing in the logs of February 7-11. Because of further fluid chemical attack, the section of virtually zero bond extended upward, to a depth of 2697.5 m (8850 ft), with further significant decreases of bond higher in the hole.

2. GT-2 Logging. The cement-bond log in GT-2B indicated 90 - 94% bond from the bottom of the casing at 2612.1 m (8570 ft) upward to 2103.1 m (6900 ft), where the cement ended. A major deviation was noted between 2493.3 and 2475.0 m (8180 and 8120 ft), where the bond varied from 70 - 90%. These depths are the approximate locations of the underreaming and sidetracking operation for GT-2A; the caliper log shows an enlargement of the borehole between 2471.9 and 2481.1 m (8110 and 8140 ft).

TABLE IV
DURATION OF PACKER USE

Date (1977)	Setting Depth [m (ft)]	Ambient Rock Temperature		Time In Hole (h)	Time Inflated at Setting Depth (h)
		°C	°F		
May 11	2522.2 (8275)	172°	342°	31	20
May 12	2513.1 (8245)	171°	340°	25	16
June 1	2653.6 (8706)	179°	354°	17	8

Fig. 23.
Lynes packer after being pulled from 2653.6 m (8706 ft). The rubber cover sheath remained in the hole.

Fig. 24.
Comparative results of cement-bond logs in EE-1 conducted on October 27, 1975; February 9, 1977; and July 11, 1977.

From June 12 to 14, Dresser Atlas conducted extensive diagnostic logging operations in GT-2B. These logs, with their depths, are shown graphically in Figs. 25a and 25b. Sixty-four hours of drilling rig time were spent in this logging. Of this total, 30 h were spent in actual logging, 24 h in cooling the hole for the Acoustilog, and 10 h in trouble shooting. The Laterolog, Caliper, Spectralog, and Acoustic VDL were run without incident, but the Acoustilog required several attempts. Finally, the removal of the gamma-ray unit from the tool stack enabled the Acoustilog to be completed. If the malfunction of the gamma-ray unit could have been detected earlier, it would have obviated the necessity of cooling the hole for 24 h, because the Acoustilog tool later worked continuously for 6 h under the downhole conditions in which the gamma-ray unit failed.

Fig. 25.

Diagnostic logging services performed (a) February 7-11, 1977, and (b) June 12-14 and July 11, 1977.

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APPENDIX A

MAJOR FIELD EXPERIMENTS CONDUCTED AFTER ESTABLISHMENT OF GT-2/EE-1 CONNECTION

Experiment No.	Date Executed	Experiment Description	Remarks
101	11/6/75	Background temperature log in GT-2.	Temperature anomalies at about 2800 and 2880 m (9200 and 9450 ft). Bottom-hole temperature constant at 197°C.
	11/7/75	Temperature log in GT-2, pumping GT-2 at 34 liter/min (9 gpm).	Same as November 6, 1975.
102	11/12/75	Same as November 6 and 7.	Same as November 6 and 7. Measured outflow at EE-1 of 8.3 liter/min (2.2 gpm).
103	11/19 and 11/20/75	Background temperature logs in GT-2 with Kuster water sampler.	Same as November 6 and 7. Water sample taken at 2750 m (9000 ft). Water sampler failed.
104	12/2/75	Background temperature log in EE-1.	No anomalies noted. Bottom-hole temperature was 205.5°F.
105	12/3 and 12/4/75	Temperature log in GT-2 while pumping EE-1 at 34 liter/min (9 gpm).	Input EE-1: 51 500 liter (13 600 gal). Outflow GT-2: 40 500 liter (10 680 gal). 75% of outflow from GT-2 occurs at 2800 m (9186 ft), 25% occurs at 2880 m (9449 ft).
106	12/23 and 12/24/75	Flow from EE-1 to GT-2 at 130 liter/min (34 gpm), temperature in EE-1 at finish.	Input EE-1: 43 900 liter (11 600 gal). Outflow GT-2: 26 500 liter (7000 gal) at 33 liter/min (8.8 gpm). No change in temperature data.
107	1/8/76	Seismic background in EE-1 with new slimhole geophone package.	Cable head leaked, amplifiers became wet, locking arm failed.
108	1/20/76	Check out plump-bob orienting device (PBOD) with Eastman multishot.	No reliable readings with PBOD; needs modification.

Experiment No.	Date Executed	Experiment Description	Remarks
109	1/21 and 1/22/76	Induced-potential and self-potential logs in EE-1, while pumping EE-1; electrode in GT-2.	Electrode not functional. S-P probe would not pass 2990 m (9820 ft); both need modification.
109	2/11/76	Repeat of January 22 Experiment. Induced-potential and self-potential logs in EE-1, while pumping EE-1; electrode in GT-2.	Logs showed bottom of casing in EE-1 at 2930 m (9600 ft) and indicated presence of a conductive zone below the casing at the 2978- to 2981-m (9770- to 9780-ft) depth.
109A	1/23/76	Pump 22 700 liter (6000 gal) at 130 liter/min (34 gpm) into EE-1 with GT-2 shut in. Rapid vent of both holes.	Input EE-1: 22 700 liter (6000 gal). Recovery EE-1: 12 860 liter (3400 gal). Recovery GT-2: 3090 liter (817 gal).
110	1/13/76	Pump 22 700 liter (6000 gal) at 130 liter/min (34 gpm) into EE-1 with GT-2 shut in. Measure pressure decay for 20 h, then vent.	Input EE-1: 22 700 liter (6000 gal). Recovery EE-1: 1500 liter (397 gal). Recovery GT-2: 3310 liter (875 gal).
111	3/16 - 3/19/76	Determine volume of fracture system by pumping into EE-1 at various pressure levels; GT-2 shut in.	Total EE-1 input: 102 200 liter (27 000 gal). Maximum pressure in EE-1, 9.1 MPa (1320 psi); in GT-2 6.5 MPa (950 psi). Final pressure 53 h after shut in: EE-1, 4.9 MPa (705 psi); GT-2, 5.0 MPa (730 psi).
112	1/29/76	Reverse of Experiment 110.	Input GT-2: 22 700 liter (6000 gal). Recovery GT-2: 6110 liter (1614 gal). Recovery EE-1: 1760 liter (464 gal).
113	1/27/76	Reverse of Experiment 109A.	Input GT-2: 22 700 liter (6000 gal). Recovery GT-2: 12 340 liter (3260 gal). Recovery EE-1: 2180 liter (576 gal).

Experiment No.	Date Executed	Experiment Description	Remarks
114	2/4 - 2/7/76	Determine flow rate potential of GT-2/EE-1 connection with both holes pressurized to keep the fractures inflated.	Both holes pressurized in steps to about 9.0 MPa (1300 psi). GT-2 vented at rate of 55-75 liter/min while maintaining pressure in EE-1. GT-2 pressure dropped at rate of 0.17 MPa/h (25 psi/h). Total input both holes: 240 200 liter (63 470 gal). Total recovery both holes: 14 600 liter (39 520 gal). S_g measured in GT-2 at 8.5 MPa (1240 psi).
115	3/23 - 3/24/76	Conduct residence time analysis of the fracture system using sodium-fluorescein dye tracer techniques. Pump into EE-1 at a constant pressure 90 bar (1300 psi).	Injected 227 400 liter (60 080 gal) in EE-1 with 380 liter (100 gal) dye. Recovered 63% of dye from GT-2. Substantial dispersion occurred in fracture.
116	3/20 - 3/21/76	Spectral gamma log in EE-1; iodine tracer logs in GT-2 and EE-1; cement bond log in GT-2, all by Dresser Atlas.	Good logs obtained; EE-1 fracture extends from 2930 to 2950 m (9610 to 9690 ft), oriented N54W. GT-2 fracture input at point where Otis packer previously milled out.
117	3/3 - 3/5/76	Map fracture in EE-1 through analysis of seismic signals; geophones in GT-2, flowing 635 liter/min (168 gpm) into EE-1.	Orientation of the geophone package achieved. Many discrete seismic signals from different azimuths and horizons obtained.
118	4/8 - 4/9/76	Preliminary downhole test of mechanical signal source.	Geophone was inoperative; replaced. Dewar failed; replaced.
118A	4/22/76	Rerun.	Arm could not be activated; repaired cable head.
118A	4/26/76	Rerun.	Test successful; good seismic signals recorded at all settings.

Experiment No.	Date Executed	Experiment Description	Remarks
119	4/27 - 4/29/76	Conduct residence time analysis of the deflated fracture system using sodium-fluorescein dye. Pump into EE-1 at a constant pressure of 4.9 MPa (700 psi).	Injected 119 400 liter (31 540 gal) into EE-1 with 6.8 liter (1.8 gal) concentrated dye. First dye appeared in GT-2 about 9450 liter (2500 gal) after maximum short-circuit time. Recovered 91% of total injection.
120	5/11 - 5/14/76	Maintain GT-2 outflow of 38 liter/min (10 gpm) while pumping into EE-1 at constant pressure of 9.3 MPa (1350 psi); confirm minimum earth stress value.	Steady-state pressurized circulating flow established; overall fracture system flow impedance, 28 bar/liter/s (26 psi/gpm). Total injection: 691 600 liter (182 730 gal). Recovery on May 26: 551 700 liter (145 750 gal); 79.8%.
121	4/19/76	Measure characteristics of GT-2 fracture and time constant for flow between GT-2 and EE-1. Pump into GT-2 with EE-1 vented; maintain pressure at 4.8 MPa (700 psi) for 4 h; shut in GT-2 and monitor pressure decay.	Feature characteristics essentially unchanged from previous experiments; flow impedance still large; flow time estimated at 10 min or less.
122	5/6/76	Map EE-1 fracture by inflating it and recording acoustic signals in GT-2 at three different depths. Measure impedance with a series of stepped flow tests.	Pressure response noted in GT-2 about 70 s after start of pumping in EE-1. Many problems with late contractor arrival, lightning strikes, power outages, faulty geophones. Experiment terminated early.
122A	5/10/76	Continuation of Experiment 122; pumped into EE-1 at flow rates from 795 liter/min (210 gpm) to 80 liter/min (21 gpm) with GT-2 vented.	Total injection: 156 600 liter (41 380 gal). Pressure rise in GT-2 leveled at 7.6 MPa (1102 psi) for 1 h; repeated and confirmed Experiment 117.

Experiment No.	Date Executed	Experiment Description	Remarks
125	6/2/76	Measure values of $A\sqrt{k}$ for EE-1, GT-2, and combined system. Pump 160 liter/min (43 gpm) into each hole separately and simultaneously; measure pressure response.	Total injection: 14 650 liter (3870 gal). $A\sqrt{k}$ value for GT-2 and EE-1 remained essentially unchanged. During combined flow into both holes, 60% went into EE-1, 40% into GT-2.
126	5/27/76	Assess performance and characteristics of mechanical seismic source (wall-banger).	Acoustic signals obtained at all tested depths in EE-1.
127A	6/16 - 6/17/76	Ranging experiment to determine depths to specific horizons in each hole, and to calculate relative positions of the two holes. Geophone fixed in GT-2, energy source moved in EE-1.	Equivalent horizons between the two holes determined within ± 1 m (± 3 ft); preliminary value of minimum GT-2/EE-1 hole spacing at -200 m (-650 ft) sea level elevation is about 14 m (46 ft).
127B	7/8/76	Ranging experiment to calculate relative positions of the two holes. Both geophone and energy source were moved simultaneously to equivalent horizons in each hole.	Results of Experiment 127A confirmed.
129A	6/22 - 6/24/76	Obtain additional micro-seismic data for further mapping of EE-1 fracture. Pump into EE-1, with geophone package and Sperry-Sun orienting device in GT-2.	Two failures of the armature springs in the locking arm motor occurred, but a sufficient number of acoustic signals for mapping the EE-1 fracture was obtained.
129B	6/29/76	Continuation of Experiment 129.	Additional signals were observed during inflation of the EE-1 fracture; no equipment problems. Total injection: 190 500 liter (50 320 gal).
131	6/7 - 6/13/76	Calibrate lengths of logging cables on GT-2 and EE-1 cable hoists.	Cables now marked to determine precise depths ± 0.6 m (± 2 ft) in each hole.

Experiment No.	Date Executed	Experiment Description	Remarks
133	7/19 - 7/21/76	Measure flow impedance at high pressure and several flow rates while pumping EE-1; verify S_3 value; measure EE-1 thermal conductivity and GT-2 fracture outlet temperature.	A large leak developed into the GT-2 annulus between depths of 2748 and 2774 m (9015 and 9100 ft) through the cemented space outside the scab liner.
134	7/27/76	Background temperature log in EE-1 to check temperature anomalies seen in Experiment 133.	Large temperature anomalies noted at depths of 2743 and 2896 m (9000 and 9500 ft).
135	7/29/76	Determine impedance of new flow path between GT-2 wellbore and GT-2 annulus, created by Experiment 133.	Larger volume of $A/\bar{K}$ may indicate fracture had grown bigger; a significantly lower impedance of 33 bar/liter/s (30 psi/gpm) was measured for the system.
136	8/4 - 8/5/76	Locate various impedances in GT-2/EE-1 system with flow path in GT-2 annulus. Flow in EE-1 with (1) GT-2 wellbore and annulus shut-in, (2) GT-2 wellbore flowing annulus shut-in, (3) GT-2 wellbore shut-in annulus flowing, (4) GT-2 wellbore and annulus flowing.	Analysis of flow data confirms a change in flow impedance and direction in the EE-1/GT-2 flow related to the recent fracture entrance effects.
123	8/12/76	Test the Reynolds downhole high-temperature detonator package in the EE-1 borehole and conduct ranging experiments 2869.4 - 2893.8 m (9414 - 9494 ft).	The Reynolds detonator package tested successfully on the surface but failed at the 2869.4-m (9414-ft) depth. A redesign of the mechanical structure is required.
140	8/24 - 8/27/76	Repeat and confirm ranging of EE-1/GT-2 borehole position.	This experiment was conducted using the less desirable lead-azide type detonators. Signals were obtained with 5 out of 6 shots and preliminary results were obtained.
142	9/16/76	38-liter (10-gal) bailer and double water sampler was tested in EE-1 at	38-liter (10-gal) bailer operated satisfactorily. The water sampler took two

Experiment No.	Date Executed	Experiment Description	Remarks
142 cont.		depths of 1524 and 2743 m (5000 and 9000 ft).	samples at 1524 m (5000 ft) but no samples at 2743 m (9000 ft).
143	9/23/76	Ranging experiment GT-2/EE-1. Fired 6 detonators in EE-1 at 91-m (300-ft) intervals from 2195 to 2652 m (7200 to 8700 ft). Geophone package and Sperry-Sun orientation in GT-2.	All equipment performed satisfactorily. All shots fired and good signals recorded.
143B	9/30/76	Ranging experiment GT-2/EE-1. Fired 6 detonators in EE-1 at several depths from 2621 to 2732 m (8598 to 8964 ft).	Again all equipment performed satisfactorily.
144	10/7/76	Temperature log of GT-2 borehole from ground level to bottom of hole using thermopile sensor.	Complete temperature log was obtained.
145	10/14/76	Ranging experiment to obtain more precise measurements of acoustic velocity in the granite rock at depths of previous experiments. Detonators were fired at depths of 2749, 2770, 2863, and 2770 m (9019, 9089, 9392, and 9089 ft).	Good signals were recorded with the geophone package in GT-2.
144B	10/21/76	Temperature log of EE-1 borehole, again using thermopile sensor.	Complete temperature log was obtained.
146	10/27/76	Ranging experiment to confirm P-wave travel time of previous experiments. Detonators were fired in EE-1 at depths of 2769, 2732, 2697, 2658, 2621, and 2585 m (9083, 8964, 8845, 8719, 8600, and 8481 ft).	Good signals were recorded with the geophone package in GT-2. The locking arm in the geophone package would not retract, preventing the package from being lowered in the borehole. Readings could be obtained by moving the package up the hole only.
137	11/1 - 11/11/76	Preleaching flow test to provide a background flow for the Na ₂ CO ₃ leaching experiment. Secondary	All equipment functioned properly, and test parameters were established. Preparations were made to

Experiment No.	Date Executed	Experiment Description	Remarks
137 cont.		objectives were to obtain time variations of the GT-2 effluent water chemistry, long-term flow impedance values to test the water treatment equipment, and determine fracture volume and residence time using a sodium-fluorescein dye tracer.	proceed with the Na_2CO_3 leaching.
138	11/11 and 11/18/76	Dowell pump truck was plumbed in to commence pumping the Na_2CO_3 solution. Pumping continued through 11-17. EE-1 was shut in on 11-17 at 8.3 MPa (1200 psi). Venting through GT-2 was monitored, and sampling of the effluent continued for several days.	All equipment functioned properly.
149	12/2/76	Magnetic ranging to determine the relative positions of the two boreholes using a permanent magnet as the source in EE-1 and the Sperry-Sun compass in GT-2.	The compass readings showed positive deflections of 1° , which agreed with field intensity calculations. To improve resolution, a high-strength electromagnet will be used to repeat the experiment.
150	12/9/76	Acoustic ranging. The large geophone package (large-diameter sonde with multiple geophones) was deployed in EE-1 with the detonator source in GT-2.	A seal leaked in the down-hole sonde and test was aborted.
151	12/10/76	Magnetic ranging with permanent magnet in EE-1 and a magnetometer in GT-2. The magnetometer was provided by Scientific Drilling Company (SDC) and is used for directional drilling.	The SDC tool would not operate at the high-temperature environment and test was aborted.
152	1/4/77	Mark logging cable (magnetically) and tag casing in EE-1 with casing locator.	Cable on EE-1 logging rig calibrated and depth to bottom of casing measured.

Experiment No.	Date Executed	Experiment Description	Remarks
152	1/7/77	Repeat of above for GT-2.	Cable on GT-2 logging rig calibration and depth to bottom of casing measured.
150	1/12 - 1/13/77	Ranging experiment using the large (Mark Products) geophone package (modified for better acoustic coupling). Geophone sonde positioned in EE-1 and detonators fired in GT-2.	Ranging data improved significantly with large modified geophone package. Relative hole position determined.
153	1/19/77	Electromagnetic ranging. Electromagnet source inserted in EE-1 with compass in GT-2 to confirm relative direction of boreholes.	Electromagnet damage during assembly in EE-1 tower. Test postponed.
154	1/27/77	Temperature log EE-1 borehole, 2286 - 3048 m (7500 - 10 000 ft), during flow test to investigate fluid entry paths in EE-1.	Dewar in downhole sonde ruptured and test was terminated. Repeated attempts to run this experiment but dewar ruptured each time.
157	1/28 - 1/31/77	Eastman gyro survey with heat-hardened gyroscopic survey tool.	Surveyed both GT-2 and EE-1 with the Eastman gyro using LASL logging cable.
154D	1/31 2/1/77	Background and pumping temperature logs in GT-2 and EE-1.	Troubles with new thermopile assembly prevented completion of tests.
	2/2 - 2/5/77	USGS testing of high-temperature televiewer on inflated fracture system in EE-1, and other logging tools.	Televiewer partially successful; caliper log unsuccessful; good spectral gamma logs obtained in GT-2 and EE-1.
157 cont.	2/14 - 2/16/77	Sperry-Sun gyro survey with heat-hardened gyroscopic tool.	Surveyed both GT-2 and EE-1 with Sperry gyro using LASL logging cable.
154D cont.	2/22/77	Same.	Dewar failed in EE-1 sonde, GT-2 logging cable deterioration; test cancelled.
154E	3/1/77	Temperature log of EE-1 borehole during flow.	Water leaves casing at 2926 m (9600 ft), returns up annulus, flowing into fracture system at 2789 m (9150 ft).

Experiment No.	Date Executed	Experiment Description	Remarks
156	2/7 - 2/11/77	Cement-bond log and radioactive iodine tracer study of fluid injection path in EE-1, by Dresser-Atlas. Caliper and Si/Ca logs in GT-2.	Little or no cement behind casing from 2737 to 2926 m (8980 to 9600 ft). Water flows from bottom of casing up the annulus, into the rock at 2743 m (9000 ft).
159	3/8 and 3/10/77 3/21 - 3/22/77	Shear shadow experiment to determine upward extent of fracture system near bottom of EE-1. Geophones in GT-2, detonators in EE-1, pumping into EE-1.	All equipment performed satisfactorily. The top of the fracture was determined to be between depths of ~2603 - 2682 m (~8540 - 8800 ft).
160	3/16/77	IP log to determine upward extent of fracture in EE-1. Voltage probe in GT-2, current electrode in EE-1, pumping into EE-1.	Results indicate the fracture may extend upward to a depth of 2530 m (8300 ft).
161	5/11/77	Set inflatable packer at depth of 2522 m (8275 ft) in GT-2 for fracture extension attempt.	Packer apparently leaked, flow up annulus.
162	5/12/77	Set inflatable packer at depth of 2513 m (8245 ft) in GT-2 for fracture extension attempt.	Packer held; pumped into GT-2 at 0.9 m ³ /min (5.5 bbl/min), 12.7 MPa (1830 psi).
163	5/17/77	Pumping experiment to test impedance of EE-1/GT-2A fracture system, pumping into EE-1.	An impedance of 39 bar/liter/s (35 psi/gpm) was measured; considered to be too high.
165	5/31/77	System flow impedance measurement, EE-1/GT-2B. Initial flow impedance measurement to test the GT-2B to EE-1 connection. Both a low-pressure and a high-pressure impedance value to be obtained.	An impedance of 17 - 20 bar/liter/s (15 - 18 psi/gpm) was measured.
166	6/1 - 6/3/77	Pressurization and fracture dilation at 2667 m (8750 ft) in GT-2B to improve impedance. A Lynes packer was run in GT-2 and set at 2654 m (8706 ft). Pumped into GT-2, using Western pump.	With EE-1 pumped, temperature of water discharge from GT-2 reached 130°C with a back pressure of 0.5 MPa (70 psi). A final impedance of ~10.5 bar/liter/s (~9.5 psi/gpm) was

Experiment No.	Date Executed	Experiment Description	Remarks
166 cont.		truck, at an initial flow rate of 0.16 m/min (1 bbl/min) and gradually increase to 0.8 m/min (5 bbl/min). EE-1 then shut in and plumbed for inflow at 380 liter/min (100 gpm).	measured.
167	6/7 - 6/8/77	Monitoring pressure in EE-1 while continuing to drill in GT-2. (A sudden pressure change could be used as indicator of when to initiate coring.)	A significant pressure response was noted initiating a coring procedure.
168	6/9/77	Dynamic temperature logs (under GT-2 and EE-1 fluid injection). Temperature measurements to determine the flow rates into the fracture intersections in GT-2B and to determine whether the high-pressure fracture extension experiment (166) had affected EE-1 connections.	Four temperature logs were successfully run in GT-2B and intersection parameters measured. Temperature logs were also run in EE-1 under inflow with GT-2 shut in.
169	6/16/77	System impedance test. Pumping from EE-1 to GT-2 at 800 liter/min (210 gpm) to obtain an estimate of the overall system impedance, before casing GT-2.	Flow test run using the Western pump to deliver 0.8 m ³ /min (5 bbl/min) into EE-1. This experiment was followed immediately by Experiment 170.
170	6/17/77	GT-2 injection temperature log. Measurement to identify and measure the rates of flow into each of the GT-2B intersections.	Water was pumped into GT-2 for a total of 9 h at a flow rate of 0.16 m ³ /min (1 bbl/min). Temperature logs were run in GT-2B during flow.

APPENDIX B
A PROGRAM FOR REDRILLING AT FENTON HILL*

SUMMARY

We recommend that both the EE-1 and GT-2 fracture systems be drilled into. First priority should be given to Plan I, which is designed to assure intersection with any EE-1 fractures originating at a measured wellbore-to-formation connection at 2758 m (9050 ft). Plan I requires at least two drilling paths from GT-2, totalling 457 m (1500 ft). One of these paths would terminate in an EE-1 seismic feature found during Experiment 129. Fracture/Feature intersection would be determined from the depressurization of the constantly pumped EE-1 well or from a significant imbalance between the GT-2 Kelly hose and return flow rates. Should fracture intersection not be obtained, provision should be made to take remedial steps by either extending the present EE-1 fracture, fracturing from the redrilled GT-2, or initiating a new fracture from the bottom of EE-1.

Should none of the above be successful, Plan II should be followed. GT-2 would now be drilled into the well-defined GT-2 seismic feature and then extended to 2896 m (9500 ft). After moving the drilling rig, EE-1 would be drilled through the GT-2 wellbore fracture originating at 2804 m (9200 ft) (if it exists), through the seismic zone, and then extended to 3017 m (9900 ft). Should a low-impedance connection not be obtained, the drilling extensions would provide a "new lab" in which fracture initiation and extension to intersection could be attempted.

As much as 1006 m (3300 ft) of directional drilling plus 183 m (600 ft) of conventional drilling may be required. This drilling should be guided by conventional means: the "EYE" and single-shot magnetic surveys. Discrete checks should be made with directional-acoustic logging. Should discrepancies occur, multishot magnetic and gyro surveys should be run.

In the sections to follow (not included here), more detail and the background information that led to our recommendations are provided. Section 2 assesses our present knowledge of the downhole systems. Section 3 presents our choice of intersection targets and provides the rationale behind our selections. Section 4 presents the detailed trajectories of the directional drilling distances, and fracture location uncertainties are discussed here. Finally, the specific drill-

*Office Memorandum dated March 1, 1977 from the Redrilling Task Force.

ling operations are discussed in Sec. 5. Cementing and kick-off procedures are presented; contracted and third-party services are anticipated; schedules and costs are estimated.

REDRILLING TASK FORCE

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Fig. B-1.
A program for redrilling at Fenton Hill.

APPENDIX C
SPECIFICATIONS OF NOBLE DRILLING COMPANY
DRILLING RIG N-115

Rig: National 110-M drawworks, with hook load capacity of 3904 m (860 000 lb), and 152-cm (60-in.) hydromatic brake.
Power: 1.1 MW (1500 hp)
Pumps: No. 1 - Emisco D1000; No. 2 - National G700.
Drilling Range: 3353 - 4877 m (11 000 - 16 000 ft).
Hoisting Drum: 63 by 127 cm (27 by 49 in.).
Drill Pipe: 3048 m (10 000 ft) of 11.4-cm (4-1/2-in.) diam.

APPENDIX D
JOB DESCRIPTION FOR LASL DRILLING MANAGER
WORKOVER/DRILLING ACTIVITIES AT FENTON HILL SITE

The LASL drilling manager's first responsibility will be the safe and efficient prosecution of the planned workover/drilling operations at the Fenton Hill site during the late fall and winter of 1976-77 (as described in the attached specifications). This responsibility will include the direction and coordination of all drilling-related aspects of the numerous anticipated LASL-planned and -directed flow tests and other associated experiments with the present (or subsequently formed) hydraulic fracture system connecting holes GT-2 and EE-1 at depth, as well as other related downhole geophysical measurements.

The drilling manager must be very familiar with all aspects of drilling-related operations in deep hard formations with a rotary drill rig of the approximate size of a National 80B. He must particularly be experienced in the following areas:

1. Directional drilling operations using a Dyna-Drill assembly.
2. Running, setting, and retrieving inflatable (Lynes-type) open-hole packers.
3. Rotary drilling in both very hard and hot formations (up to 400°F).
4. Conventional hydraulic fracturing operations.

5. The running and setting of deep strings of large-diameter casing.
6. Cementing operations in deep holes with excessive bottom-hole temperatures.
7. Remedial casing operations including the cutting (or milling-out) and subsequent removal of existing casing strings.

The LASL drilling manager will report directly to the Fenton Hill site manager (or in his absence, the Q-12 group leader), and will be on call during the entire workover/drilling operation except on leave of absence as authorized by the site manager.

The LASL drilling manager will direct and coordinate the operations of the drill rig and crews through the contractor's rig manager — tool pusher — so that the objectives of this phase of the LASL HDR geothermal project, as outlined in the attached specifications and related documents are accomplished. To this end, it is desirable that the LASL drilling manager also be available during the immediate predrilling phase of the workover/drilling operations, so that he can adequately interact with appropriate LASL staff in the final phases of planning for this operation.

The LASL drilling manager will prepare a brief daily report, to augment and clarify the contractor's normally very terse daily drilling report. This report will stress drilling-related activities for that day including any experimental interactions or support, and should provide quantitative information whenever possible (for example, accurate depths or intervals for hole surveys and logs; packer setting depth and time, pressure variation, and time and mode of packer failure; casing tally, setting depth, terminal hook load, and related dimensional data for the surface configuration on all casing jobs; etc.).

The LASL drilling manager will coordinate the activities of the various service company field engineers, service personnel, and other specialists with those of the drilling contractor's operating crews. Typical of the anticipated specialists and field engineers associated with this workover/drilling operation are the following:

- (a) directional drilling specialist
- (b) mud engineer
- (c) field engineer for inflatable packers
- (d) service personnel for cementing operations
- (e) casing crews
- (f) logging specialists
- (g) coring engineer

Finally, the LASL drilling manager will be responsible for receiving and inventorying all third-party equipment or materials delivered to (or removed from) the drill site. He will work with LASL's Supply and Property Department representative in maintaining a day-to-day cost breakdown. He will represent LASL in working with the contractor's representative in ordering third-party equipment and materials.