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Idaho Operations Office

COMPLETION REPORT: RAFT RIVER GEOTHERMAL PRODUCTION WELL FOUR (RRGP-4)

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EG&G IDAHO, INC.

and

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DOE-ID

February 1979

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APPROVED:

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Deputy Director
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550 Second Street
Idaho Falls, Idaho 83401

ABSTRACT

The fourth Raft River well was originally drilled to 866 m (2840 ft), for use as a test injection well. This well allowed the injection of geothermal fluids into the intermediate zone--above the geothermal production zone and below the shallow groundwater aquifers.

After this testing, the well was deepened and cased for use as a production well. The well's designation was changed from RRGI-4 to RRGP-4. This report describes the drilling and completion of both drilling projects. Results of well tests are also included.

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COMPLETION REPORT:
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(RRGP-4)

I. INTRODUCTION

This report describes the drilling of Raft River Geothermal Injection Well Four (RRGI-4), as well as the eventual modification of the well for use as a production well (RRGP-4). Previous Raft River wells established the feasibility of using the valley's geothermal resource for a 5-MW power plant and for various nonelectric applications. RRGI-4 was used as an experimental injection well, to test the injection of spent fluids into the intermediate-depth aquifer. The well was later deepened with multiple legs and converted into a production well, RRGP-4.

RRGI-4 was sited near RRGE-1, to test the effects of intermediate injection on the production zone while providing an optimum location for later conversion to production status (see Figure 1 and 2). Drilling began April 18, 1977, and RRGI-4 was completed on May 4, 1977, to a depth of 866 m GL[a] (2840 ft referenced to ground level). RRGP-4 drilling began on September 21, 1978, and was completed on November 15, 1978. Two legs were drilled to depths of 1652 m GL (5420 ft) and 1558 m GL (5110 ft).

II. DRILLING SUMMARY

1. RRGI-4 DRILLING

The fourth Raft River geothermal well, RRGI-4, was designed for injection into the intermediate-zone aquifer. This zone was selected in order to minimize contamination of the groundwater and production aquifers, and to reduce well cost. The location was approximately 1 km (1/2 mi) south of RRGE-1. The land was available, the hydrogeology was well understood, and hydrogeologists suspected major upward leakage from the production zone. This would allow them to monitor and understand the interconnections of leaky reservoirs by alternately producing and monitoring RRGE-1 and RRGI-4. Researchers hoped injection testing would create a man-made hydro-cap, stopping the upward leakage of the geothermal production zone and thereby retarding the reservoir pressure loss incurred during full-scale field production. In addition, the reduction of well cost and injection-pump requirements was significant when compared to deep injection into the production zone.

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[a] All depths are referenced from the Kelly Bushing, 4.3 m (14 ft) above ground level, unless otherwise noted (as in this case).

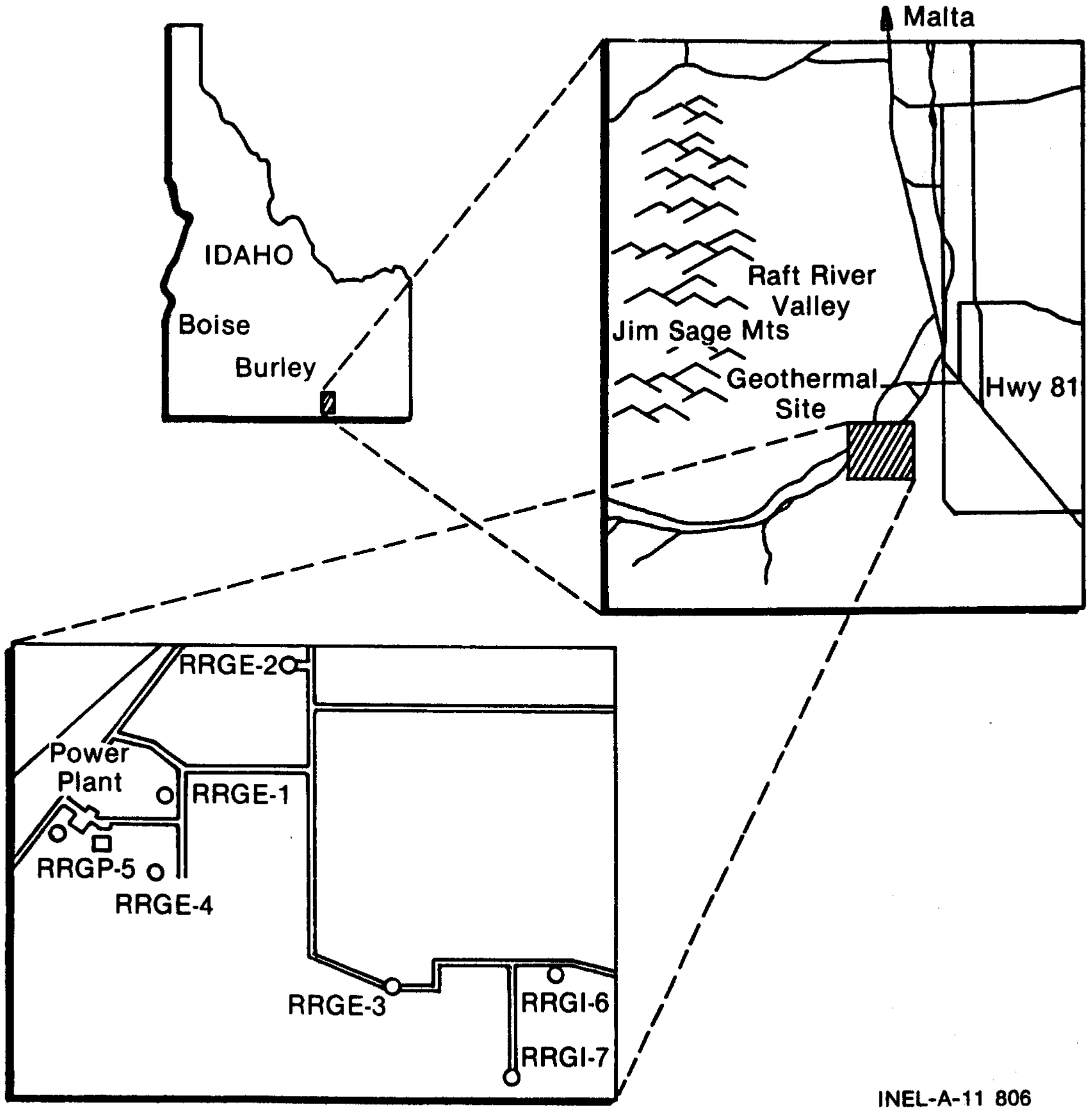

Fig. 1 Raft River geothermal site and location of wells.

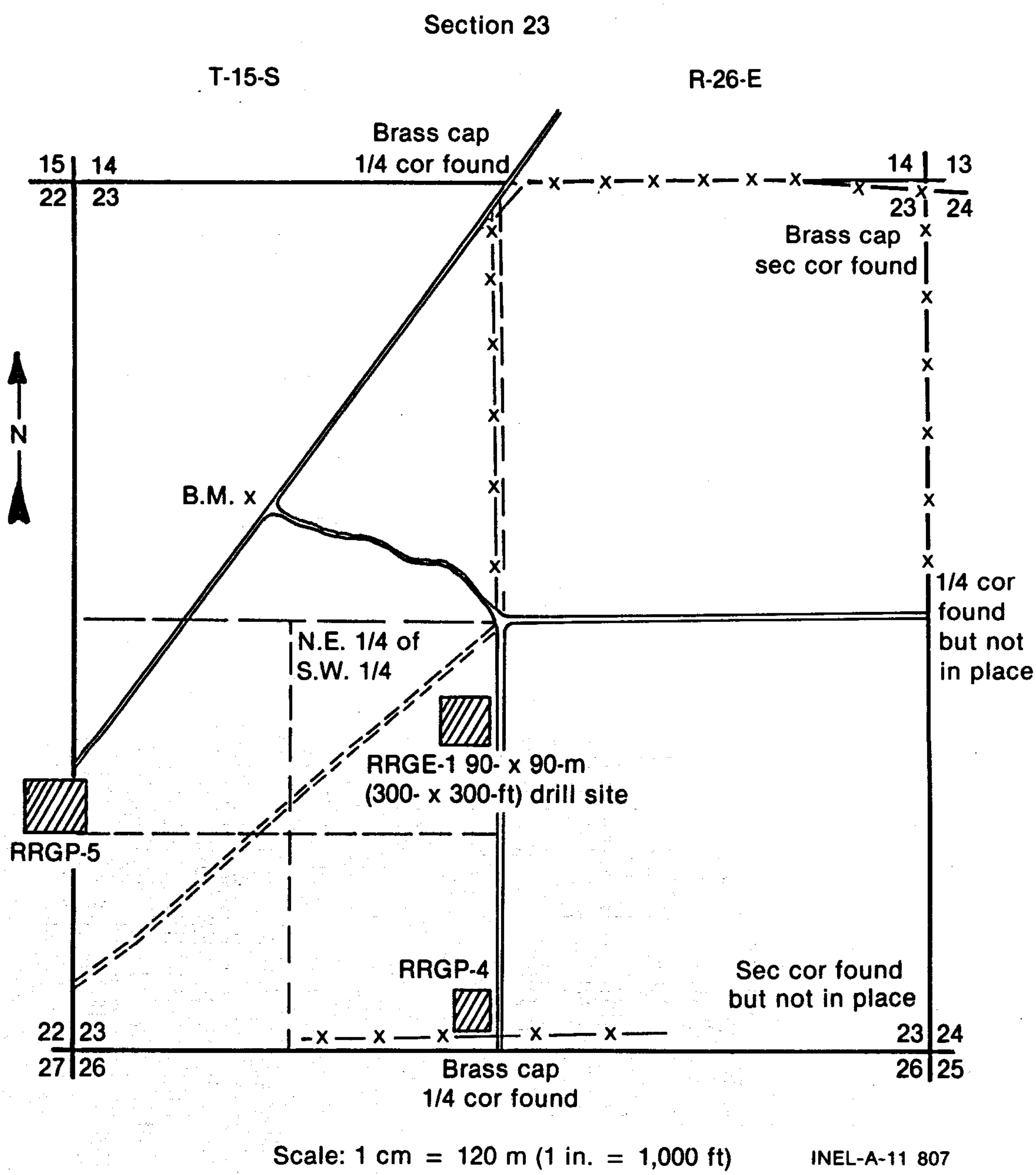

Fig. 2 Location survey.

The drill site, with approximate dimensions of 76 x 76 m (250 x 250 ft), was completed prior to rig move-on. The site preparation included excavation of a fluid reserve pit; leveling, grading, and graveling of the site; and road construction. A temporary water line from RRGE-1 to the site provided drilling water.

A dry-hole digger drilled a 91-cm (36-in.) diameter hole and set 12 m (40 ft) of 76-cm (30-in.) diameter conductor pipe. This contractor cemented the pipe with plant-mix concrete. The dry-hole digger also drilled the rat and mouse holes. A sub-contractor constructed a 2.4- x 2.4- x 3-m (8- x 8- x 10-ft) concrete-lined cellar around the conductor pipe.

Procurement was completed by the end of March, and drilling began on April 8, 1977. Colorado Well Service, of Rangely, Colorado, was awarded the drilling contracts. The rig, Rig 99, was a truck-mounted Cabot 900 with a 4-m (14-ft) substructure and a hoist capacity of 136,000 kg (300,000 lb).

The surface hole was drilled with a 38-m (15-in.) bit and reamed to 66 cm (26 in.). On April 10, 1977, 122 m (400 ft) of 51-cm (20-in.), K-55, 140-kg/m (94-lb/ft) surface casing were set.

A 31-cm (12-1/4-in.) hole was drilled to 582 m (1909 ft). It was reamed to 44 cm (17-1/2 in.) after logging and coring the hole. Drillers attempted to core at a depth of 577 m (1894 ft), using the Joides quadracone core-bit system on loan from LASL. During the trip into the hole with the corebarrel, the 30-cm (12-in.) OD corebarrel stabilizer became stuck at 438 m (1436 ft). Backoff shot service was used to disengage the drill pipe from the coring assembly. The fish was recovered by using jars and bumper sub to free the stabilizer. Dresser-Atlas and the U.S. Geological Survey ran logs of the hole. Coring was again attempted, recovering 1 m (42 in.) of core.

At a depth of 580 m (1901 ft), 34-cm (13-3/8-in.), K-55, 81-kg/m (54.5-lb/ft) casing was run and stage-cemented. The shoe was drilled out with a 31-cm (12-1/4-in.) bit and drilling proceeded to a depth of 643 m (2110 ft). At this depth it was necessary to trip out for a new bit. A prior decision had been made to cut a core at selected intervals which coincided with trips for new bits. During the trip in with the corebarrel, however, an obstruction was encountered at 575 m (1887 ft). Milling tools were used, but they only sidetracked around the fish. Logging determined the fish to be the 34-cm (13-3/8-in.) casing shoe, float collar, and two joints of casing, which had parted and fallen 20 m (67 ft). A fishing-spear attempt was made to jar the fish loose and let it fall downhole, hopefully creating a more vertical entry through the casing. The fish could not be moved. Three attempts to pass the bit and string through the parted casing were successful, enabling drilling to proceed to a depth of 860 m (2820 ft). A second core was cut from 860 to 866 m (2820 to 2840 ft).

Predrilling parameters limited total depth to either 1060 m (3500 ft)or the depth at which bottom-hole temperature would reach 121°C (250°F). Temperature logs taken during this period showed temperatures of 114°C (237°F) at the top of the parted casing, and 122°C (252°F) at 823 m (2700 ft). Logs are shown in Figure 3. Artesian flow had reached about 18 L/sec (300 gpm). The decision was made to terminate drilling.

Prior to releasing the rig, four joints of 24-cm (9-5/8-in.) casing were passed through the parted 34-cm (13-3/8-in.) casing to verify that the well could be deepened and completed as a production well at a later date. Short injection tests were run to verify predicted injection capacities of the well.

2. RRGP-4 DEEPENING

On September 21, 1978, the well was reentered and the second phase of drilling was begun. The project is summarized in Figure 4. Since the two bottom joints of casing could not be dislodged earlier, the decision was made to drill around them. Only minor problems were encountered getting around the casing, since the bit usually veered to the side.

Casing was run and cemented from 1954 m (3457 ft) up to the 24-cm (9-5/8-in.) casing hanger at 461 m (1512 ft). A cement bond log (CBL) indicated little or no bonding from 560 m (1837 ft) up to casing hanger. Two hundred sacks of cement were mixed and squeezed down through the fluted-casing hanger. A second CBL indicated no bond from 558 to 523 m (1830 to 1715 ft) and 20% bond from 523 to 461 m (1715 to 1512 ft). Cement was drilled out to above the shoe and the BOP-casing system was pressure-tested to 1.2 x 10^6 kg/m^2 (1700 psi) with the Halliburton pumper truck. The shoe was then drilled through to 1082 m (3550 ft) in preparation for whipstocking. Using a turbodrill, the hole was drilled to 1098 m (3602 ft). The hole gained angle--up to 10.5 degrees in the N5W direction at a depth of 1175 m (3853 ft). The hole seemed tight in several locations, so the hole was reamed to the bottom.

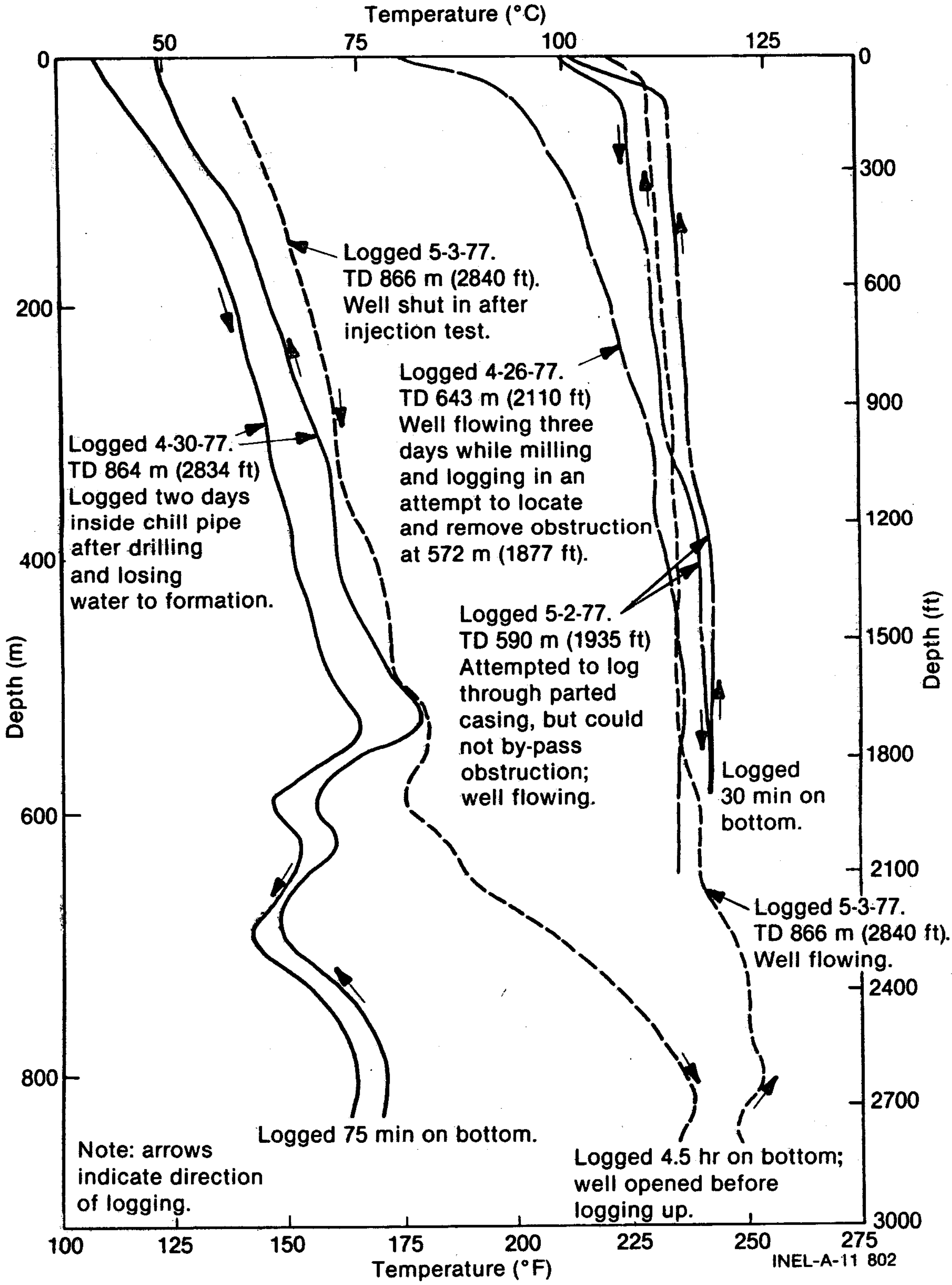

Fig. 3 Temperature logs.

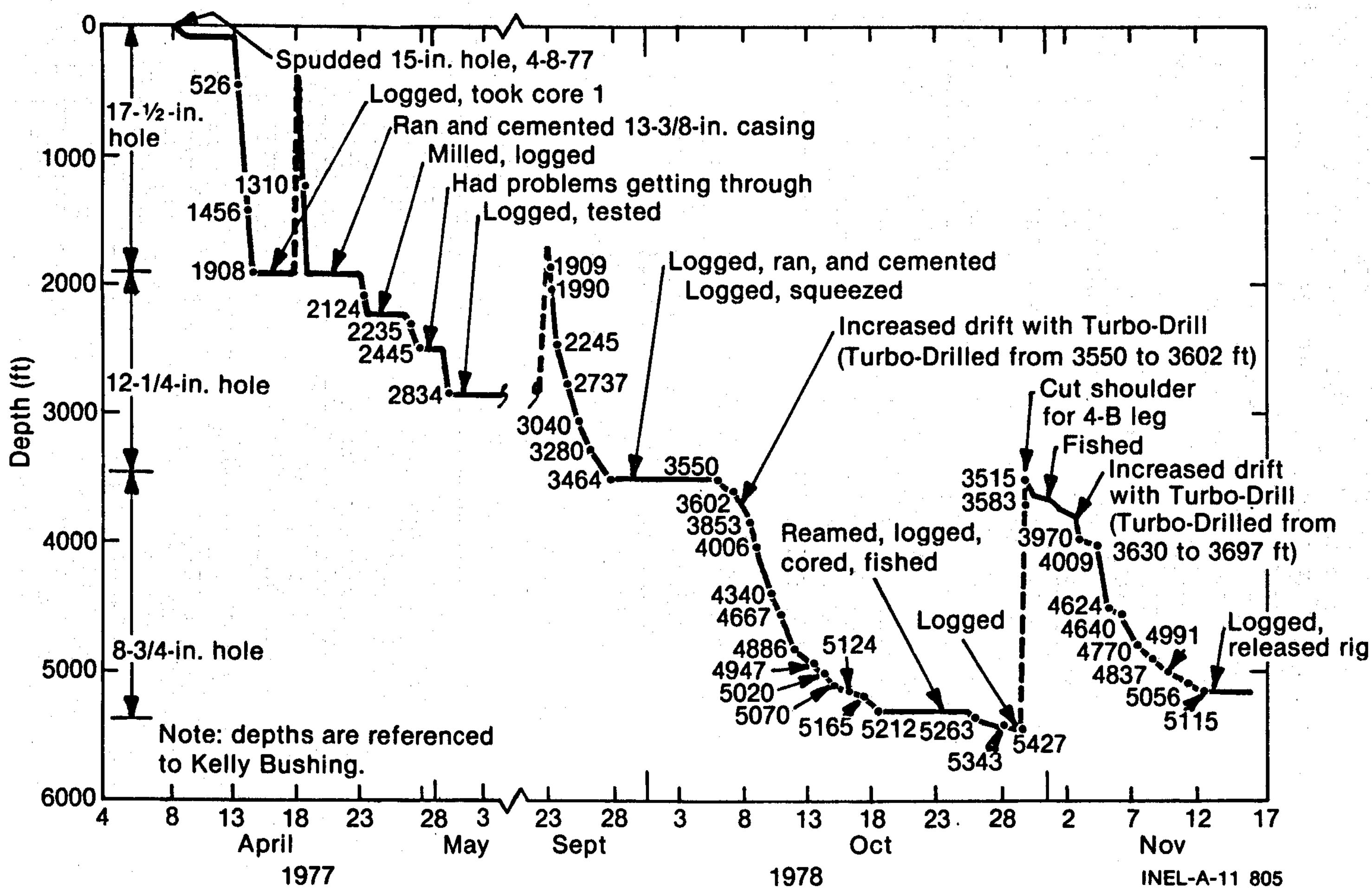

Fig. 4 Drilling and operations summary.

During the drilling and surveying to 1589 m (5212 ft), a key seat formed. The hole was reamed from 1128 to 1167 m (3700 to 3830 ft). Also, the last 2 m (5 ft) of the hole were tight and caused some sticking problems. The hole was logged, but the logger lost an acoustic tool in the well. Several fishing runs were made before most of the tool was recovered. The remainder of the tool was milled, and two magnet runs recovered the junk. The hole was drilled on to 1654 m (5427 ft) and logged.

During the drilling of a shoulder for the second leg, the Monel drill collar broke. On the second fishing run, the fish was recovered. The turbodrill was used to drill from 1106 to 1222 m (3630 to 4009 ft). The turbodrill was then layed down, and a 22-cm (8-3/4-in.) bit was picked up for further drilling to 1414 m (4640 ft). A 5-m (15-ft) core was cut at 1414 m (4640 ft), recovering 3 m (9 ft) of core. A second 5 m (15 ft) of core were cut at the interface of the Tertiary-Precambrian, recovering 2 m (7 ft).

The hole was then drilled to 1559 m (5115 ft) and cleaned for logging. After logging, an attempt was made to get back in leg A using the turbodrill, Monel drill collar, and a 2-degree kick sub. The attempt failed and the rig was released. Figure 5 illustrates the current status of RRGP-4.

III. SURFACE AND CONTAINMENT EQUIPMENT AND SERVICES

1. CONTAINMENT EQUIPMENT - SURFACE HOLE

A 51-cm (20 in.) single-gate Shaffer blowout preventer was set between the 51- x 30-cm (20- x 12-in.) expansion spool and drilling nipple, for drilling the 44-cm (17-1/2-in.) hole to 582 m (1909 ft).

2. CONTAINMENT EQUIPMENT - PRODUCTION HOLE

After setting the 34-cm (13-3/8-in.) casing at 579 m (1901 ft), the following containment stack (listed from expansion spool up) was used (see Figure 6).

(1) WKM 51- x 30-cm (20- x 12-in.) expansion spool

(2) WKM 30-cm (12-in.) master valve

(3) Adaptor spool

(4) Shaffer double-gate 30-cm (12-in.) BOP

(5) Hydril Type-GK 30-cm (12-in.) BOP

(6) Grant 30-cm (12-in.) rotating head.

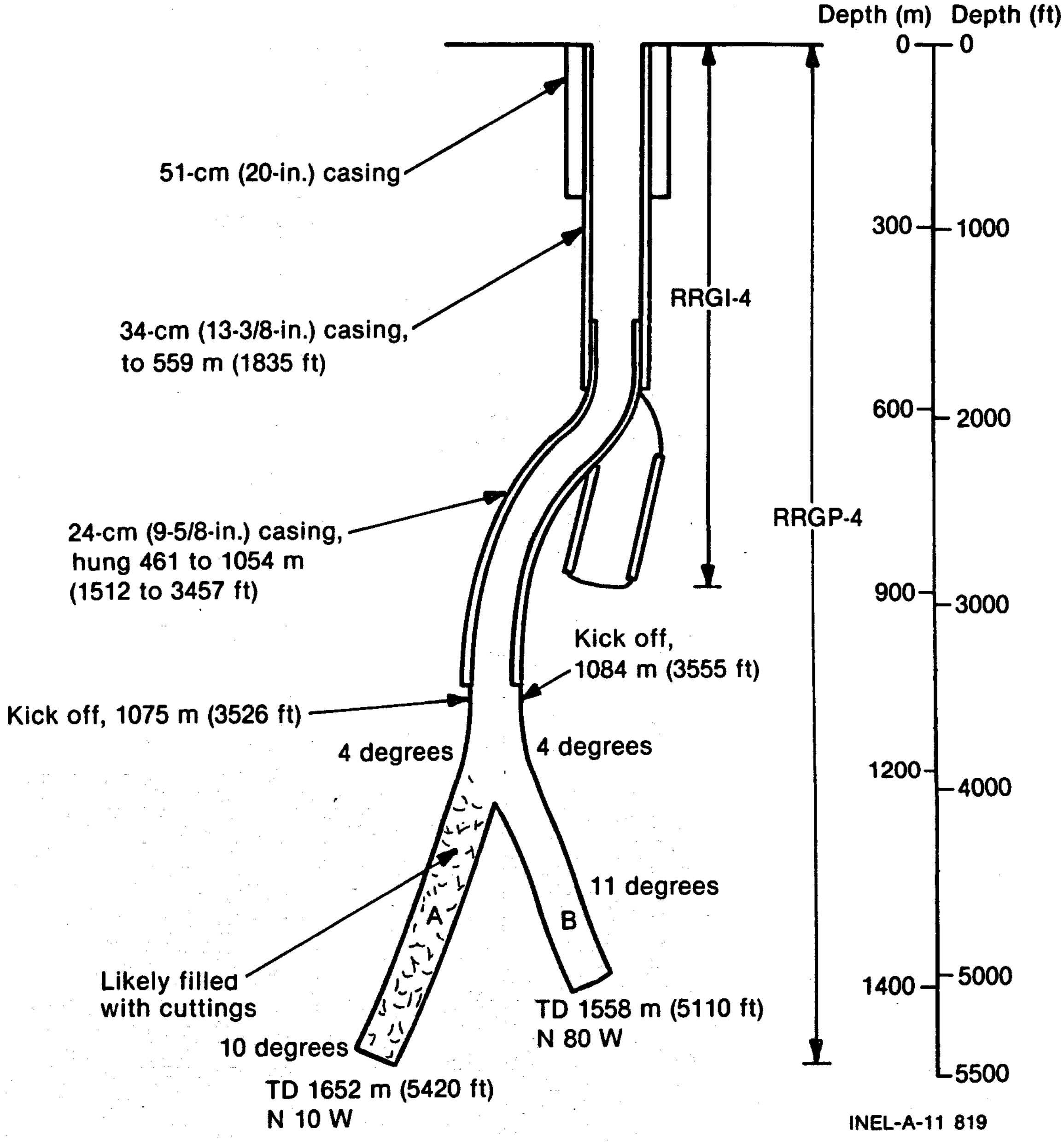

Fig. 5 Subsurface well status.

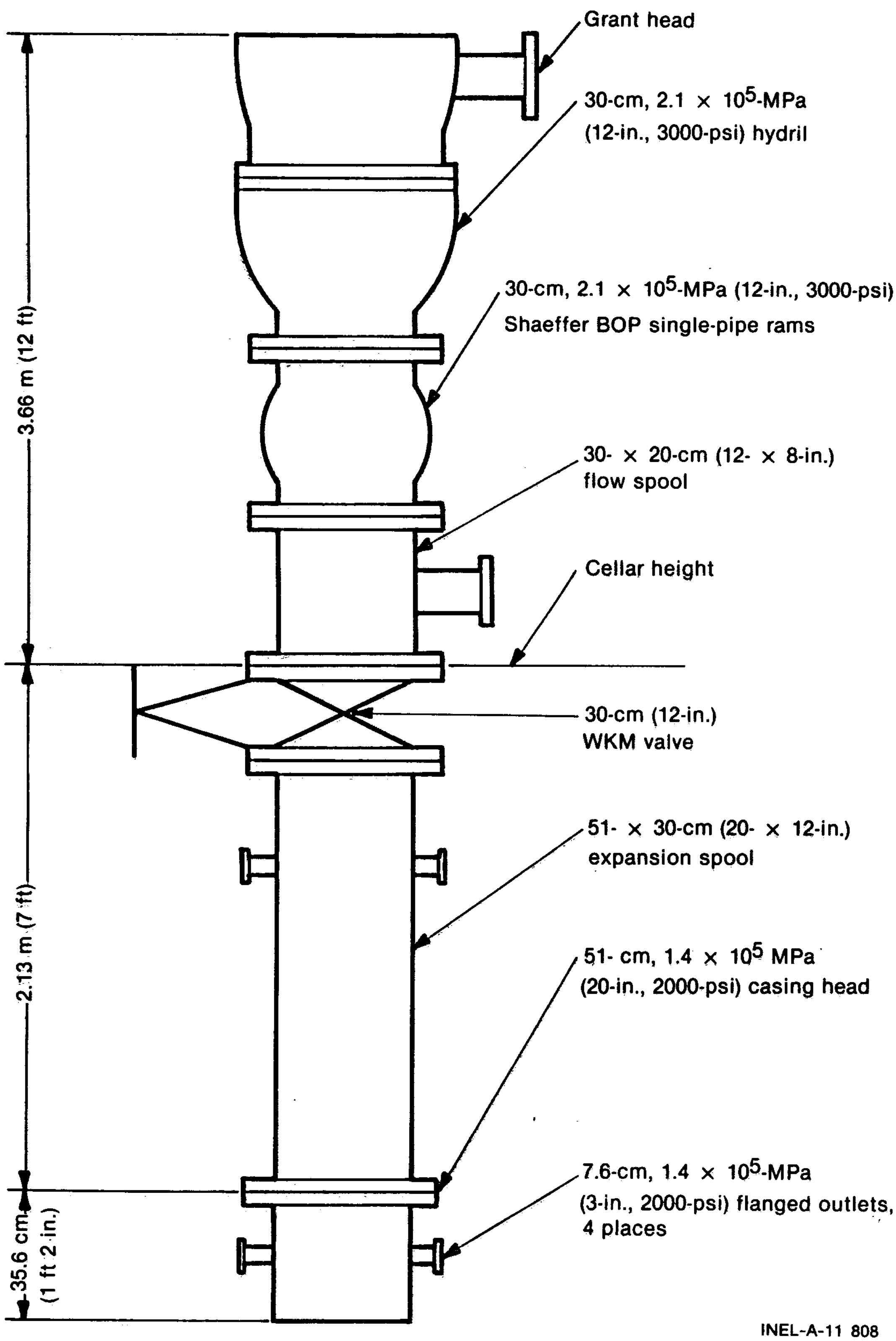

Fig. 6 Containment equipment.

3. CELLAR

A 2.4- x 3.0- x 2.4-m (8- x 10- x 8-ft) reinforced-concrete cellar was built to accomodate the BOP stack.

4. DRILLING RECORDER

A geolograph drilling recorder was used during drilling to record depth, penetration rate, bit weight, and pump pressure.

5. WELLHEAD

The permanent wellhead on this well consists of a standard WKM wellhead system. The casing head, with its 51-cm (20-in.) 141-kg/cm^2 (2000-psi) API flange, is welded directly to the 51-cm (20-in.) well casing. The expansion spool mates to the 51-cm (20-in.), 141-kg/cm^2 (2000-psi) API casing head flange on the bottom and the 30-cm (12-in.), 28-kg/cm^2 (400-psi) ANSI flanged master gate valve on the top. Both sides of the expansion spool contain 7.5-cm (3-in.) valved outlets with 7.5-cm (3-in.), 141-kg/cm^2 (2000-psi) API flanges.

A hanger spool mates with the master valve on the bottom, and with a 20-cm (8-in.), 42-kg/cm^2 (600-psi) ANSI flanged power-seal gate valve on top. Above the power-seal gate valve is a 20-cm (8-in.), 42-kg/cm^2 (600-psi) ANSI tee (or cross). Expansion can be measured by monitoring the location of a 7-microcurie encapsulated cobalt-60 radioactive source embedded in the top edge of the 34-cm (13-3/8-in.) casing.

IV. DOWNHOLE EQUIPMENT AND SERVICES

1. SURFACE CASING

Ten joints of 51-cm (20-in.) H-40 casing were tack-welded at each joint, and set and cemented at 122 m (400 ft). Parrish Oil Tool ran the casing.

2. INTERMEDIATE CASING

Forty-nine joints of 34-cm (13-3/8-in.), 81-kg/m (54.5-lb/ft), K-55, range-3 casing, guide shoe, float collar, and DV tool were run by Lamb "JAM" (Joint Analyzed Make-Up) system. The second joint up from the guide shoe did not make up well. It showed torquing of 18,440 N·m (13,600 ft-lb). The average joint torque was 9220 N·m (6800 ft-lb). The 18,440-N·m (13,600-ft-lb) torque could have resulted from the threaded ends butting against each other.

3. PRODUCTION CASING

Forty-eight joints of 24-cm (9-5/8-in.) casing were run and cemented from the casing hanger from 461 to 1054 m (1512 to 3457 ft). The casing was Type K-55, 54 kg/m (36 lb/ft) BT&C, Range 3.

4. DRILL BIT SUMMARY

A 38-cm (15-in.) hole was drilled to 124 m (407 ft) with a Security S3J bit, then reamed to 66 cm (26 in.) with a Smith hole opener. A 31-cm (12-1/4-in.) hole was drilled from 122 to 579 m (400 to 1901 ft) with Smith nonsealed bearing bits. The hole was then reamed with a 44-cm (17-1/2-in.) hole opener. A 31-cm (12-1/4-in.) hole was drilled to 866 m (2840 ft) with water, and completed open hole.

When the rig moved back over the hole to complete it as a production well, the hole was deepened to 1056 m (3464 ft) with four Smith Type-SVH, 31-cm (12-1/4-in.) bits and one Hughes Type-OWVJ, 31-cm (12-1/4-in.) bit.

After cementing, a Hughes 22-cm (8-3/4-in.) Type-JD8 bit was used to drill the cement, the shoe, and the formation to 1075 m (3526 ft)--the kickoff point for sidetracking. Two Reed 22-cm (8-3/4-in.) Type-F31GJ bits were used on the turbodrill to sidetrack 100 m (327 ft) of hole.

Nine bits were used to drill from 1174 m (3853 ft) to 1654 m (5427 ft). These included one Reed Type-F34J, three Security Type-M84F, two Security Type-H-100F, and three Hughes J-77 bits. One of the Hughes J-77 bits was a rerun bit.

A Hughes XDV and a rerun Reed bit were used to build a shoulder for Leg B. During the sidetracking, a Reed 22-cm (8-3/4-in.) Type F34J drilled 12 m (41 ft). Another Reed Type F31G was used to ream the shoulder and new hole, and a third Reed Type F31G was used with the turbodrill to sidetrack an additional 95 m (312 ft).

After drilling 192 m (631 ft) with a Security S-88, two cores were taken using two Hycalog 20-cm (7-7/8-in.) bits, each coring 5 m (15 ft). Two Hughes Type J-77 and two Security Type H-100F were used to complete the second leg to 1559 m (5115 ft).

5. CORING

Two cores were recovered from the upper part of the (RRGI-4) hole using a Joides 20-cm (8-in.) OD x 9-m (30-ft) long corebarrel. The Joides system components were loaned to the INEL by Los Alamos Scientific Laboratory (LASL) and Scripp Oceanographic Laboratory. The system is comprised of a 20-cm (8-in.) marine corebarrel and a 25-cm (9-7/8-in.) Smith tungsten-carbide 4-cone bit. The cut core is 5.7 cm (2-1/4 in.) OD. This system was developed by Scripp for coring the ocean bottoms. It was used with high recovery on the LASL Hot Dry Rock Project, coring granitic rock. It had not previously been tried in the sedimentary rock which occurs at Raft River. Recovery percentage was better in the deeper, more indurated sediment.

The first core attempt occurred at a depth of 577 m (1894 ft). The 31-cm (12-1/4-in.) corebarrel stabilizer stuck at 442 m (1450 ft). Apparently either a dogleg or out-of-gauge hole caused the problem. On reentry with a 28-cm (11-in.) stabilizer, a core was successfully taken. Coring depth was from 577 to 579 m (1894 to 1901 ft); recovering 1 m (3.5 ft) of micaceous sandstone.

A third core attempt occurred at 643 m (2110 ft) after drilling out the shoe. An obstruction occurred at 575 m (1887 ft) on the trip in the hole with the corebarrel. The obstruction was later determined to be parted casing.

Coring was not attempted again until a depth of 860 m (2820 ft). Six meters (20 ft) were cored, recovering 4 m (13 ft) of fractured micaceous sandstone and siltstone.

On the reentered well (RRGP-4), two cores were recovered in two adjacent 5-m (15-ft) intervals using Hycalog 20-cm (7-7/8-in.) bits of Types CMHIP and PC20P. Recovered core sections were 3 m (9 ft) and 2 m (7 ft) in length, taken between 1414 and 1424 m (4640 and 4671 ft). The core was taken at the interface between the tertiary and the P-C metamorphic formations.

6. DRILLING FLUID

Approximately 1 kg/L (8 to 9 lb/gal) of gel mud, viscosity 41, was used to drill the surface hole. Gel mud was used to drill the 44-cm (17-1/2-in.) hole to 579 m (1901 ft). Mud weight was held at 1.2 kg/L (9.5 lb/gal) with a viscosity of from 36 to 52 sec/1000 cm^3. Drilling below 582 m (1909 ft) was performed with water from a domestic well and the reserve pit at the RRGE-1 site.

7. SAMPLE LOGGING

A mud logging service monitoring drilling fluid and cutting returns was utilized throughout all drilling below the conductor pipe. This service monitored fluid temperatures (in and out), and hydrogen sulfide. Lithologic characteristics were also determined by analyzing the drill cuttings recovered every 6 m (20 ft). Readers of reports which have not been provided with copies of the lithologic logs may obtain copies by writing to the Office of Geothermal Energy, Idaho Operations Office, Department of Energy, 550 Second Street, Idaho Falls, ID 83401.

8. FORMATION TOPS

Formations were encountered at the following drilled depths:

	Leg A [m (ft)]		Leg B [m (ft)]	
Alluvium	Surface		Surface	
Raft River	27	(90)	27	(90)
Salt Lake	300	(1000)	300	(1000)
Yost Quartzite	1399	(4590)	---	---
Shist (Upper Narrows)	1419	(4655)	1416	(4645)
Elba Quartzite	1451	(4760)	1468	(4815)
Quartz Monzonite	1539	(5050)	1548	(5080)

9. LOGGING

Various logs were run in the RRGI-6 well in order to determine the condition of the hole at different stages of the drilling operations. A listing of the logs, the intervals, and the lengths is shown in the following tables.

TABLE I

LOG RECORD, 0 to 580 METERS (0 to 1900 FEET)

Date	Type	Depth (m)	Depth (ft)	Company
4-17-77	Compensated Neutron	122-582	401-1909	Dresser-Atlas
4-6-77	Densilog	122-581	400-1908	Dresser-Atlas
4-15-77	Dual Induction	123-575	403-1886	Dresser-Atlas
4-16-77	Acoustilog	122-580	401-1901	Dresser-Atlas

TABLE II

LOG RECORD, 550 TO 1065 METERS (1800 TO 3500 FEET)

Date	Type	Depth (m)	Depth (ft)	Company
9-28-78	Dual Induction Focused	556-1055	1824-3460	Dresser-Atlas
9-27-78	Caliper	533-1056	1815-3464	Dresser-Atlas
9-29-78	Acoustilog	555-1051	1820-3448	Dresser-Atlas
9-28-78	Densilog	555-1053	1820-3456	Dresser-Atlas
9-28-78	Densilog-Neutron	555-1053	1820-3456	Dresser-Atlas
9-28-78	ΔTemperature	0-1056	0-3463	Dresser-Atlas
10-5-78	Cement Bond	442-950	1450-3118	Dresser-Atlas
10-2-78	Cement Bond	442-990	1450-3247	Dresser-Atlas

TABLE III

LOG RECORD, LEG A,1020 TO 1650 METERS (3350 TO 5420 FEET)

Date	Type	Depth (m)	Depth (ft)	Company
10-20-78	Densilog	1058-1591	3471-5221	Dresser-Atlas
10-20-78	Caliper	1054-1585	3459-5200	Dresser-Atlas
10-20-78	Compensated Neutron	1059-1590	3474-5220	Dresser-Atlas
10-20-78	Dual Induction Focused	1052-1590	3450-5218	Dresser-Atlas
10-19-78	Temperature	1042-1594	3420-5230	Dresser-Atlas
10-29-78	Differential Temperature	1036-1652	3400-5420	Dresser-Atlas
10-20-78	Diplog	1057-1581	3467-5186	Dresser-Atlas
10-20-78	Acoustilog	1057-1587	3467-5208	Dresser-Atlas
10-18-78 to 10-30-78	Mudlog, Leg A	600-1652	1970-5420	Rocky Mountain Geo-Engineering

TABLE IV

LOG RECORD, LEG B, 1020 TO 1560 METERS (3350 TO 5115 FEET)

Date	Type	Depth (m)	Depth (ft)	Company
10-31-78 to 11-13-78	Mudlog, Leg B	1084-1650	3555-5115	Rocky Mountain Geo-Engineering
11-13-78	High Resolution Temperature	10-1563	32-5128	Schlumberger
11-13-78	Dual Induction	1058-1560	3471-5120	Schlumberger
11-13-78	Compensated Sonic	1043-1649	3421-5113	Schlumberger
11-13-78	F.B. Spinner	1029-1280	3376-4200	Schlumberger
11-31-78	Fracture I.D. Log[a]	1058-1561	3470-5124	Schlumberger
11-13-78	Compensated Neutron Formation Density	1058-1561	3470-5120	Schlumberger
11-14-78	4-Arm Caliper	1058-1561	3470-5124	Schlumberger
11-13-78	Directional	1058-1561	3470-5124	Schlumberger
10-29-78	Differential Temperature	1036-1652	3400-5420	Dresser-Atlas
10-20-78	Diplog	1064-1561	3490-5124	Dresser-Atlas
6-9-78	Flowmeter	---	0-TD	EG&G
7-5-78	Pressure	---	0-TD	EG&G
	Temperature	---	0-TD	EG&G

[a]Computer processed interpretation.

10. CEMENTING

Surface Casing -- The 51-cm (20-in.) casing was cemented in one stage with the guide shoe at 122 m GL (400 ft) with 630 sacks of 50-50 Pozmix, 35% flour, and 2% calcium chloride. Slurry weight was 1.9 kg/L (15.1 lb/gal), and yield was 0.041 m^3 (1.44 ft^3) per sack. Nine thousand liters (60 bbl) of water were pumped ahead of the slurry displacing the gel. Pumping was started at 4:05 A.M., with cement in place (CIP) at 5:20 A.M. Good circulation was maintained throughout the operation, and cement returns were obtained at the surface.

Intermediate Casing -- The 34-cm (13-3/8-in.) casing was cemented in two stages. The shoe was set at 597 m GL (1901 ft). A differential valve (DV) cementing tool was placed at 426 m (1397 ft). The cement was Class-G cement with 35% silica flour and 0.03% Hallad 9, for a weight of 1.9 kg/L (15.1 lb/gal), with 9000 L (60 bbl) of water ahead. Pumping pressure was 2000 to 3500 kPa (300 to 500 psi), increasing to 9000 kPa (1250 psi) when the plug was set. Pumping started at 8:42 P.M. with CIP at 10:10 P.M. The crew waited on cement (WOC) for 8 hours between stages. The second stage started at 7:00 A.M. with CIP at 8:15 A.M. There were 9000 L (60 bbl) of water ahead of slurry: 1013 sacks of 50-50 Pozmix, with 35% silica flour displaced by water followed by mud. Initial pumping pressures of 5000 to 5200 kPa (700 to 750 psi) jumped to 10,300 kPa (1500 psi) when the plug was bumped. Good circulation and returns were experienced throughout both cementing jobs.

11. LINER HANGER

The liner hanger for the 25-cm (9-5/8-in.) production liner was a Baash-Ross plain type, with fluted cones and circulation ports. The ports were designed to facilitate a remedial cement job if required.

Forty-eight joints of 25-cm (9-5/8-in.), K-55, 54-kg/m (36-lb/ft), BT&C casing totaling 593 m (1945 ft) were hung from the liner hanger inside the 34-cm (13-3/8-in.) casing. The liner hanger was set at 461 m (1512 ft), leaving an overlap of 123 m (403 ft) between the 34-cm (13-3/8-in.) casing and the 25-cm (9-5/8-in.) casing. The shoe of the 25-cm (9-5/8-in.) liner was set at 1054 m (3457 ft). A float collar was positioned one joint above the float shoe. (See details on centralizers in the Appendix.) All casing ends were threaded and joined with couplings. A casing crew using the "JAM" (Joint Analyzed Make-Up) system was employed to run the 25-cm (9-5/8-in.) casing.

12. DRILLING PROBLEMS

Stuck Corebarrel -- While running with the corebarrel on the first core run, the 31-cm OD (12-1/4-in.) core assembly stabilizer immediately above the corebarrel became stuck at 442 cm (1450 ft). The stabilizer was located 11 m (34 ft) above the bit. Working the drill pipe did not free the stabilizer. Dialog Shot Service was called out. While waiting on Dialog, 153,000 L (1000 bbl) of diesel oil were spotted, but the wait time was too short for the diesel to do much good. Dialog set off two string shots at 441 m (1448 ft). The drill pipe was backed off the core assembly. The hole was entered with Bowen 20-cm (8-in.) jars and bumper sub, and screwed back into the core assembly. The jars were set off and the core assembly was retrieved. A 28-cm OD (11-in.) stabilizer replaced the 31-cm (12-1/4-in.) stabilizer for future coring.

Parted Casing -- A 28-hour WOC followed the cementing of the 34-cm (13-3/8-in.) casing before drilling out the cement. Drilling took 4-1/2 hours, with casing pressure tests of 2000 kPa (300 psi). The hole was deepened to 643 m (2110 ft), when it became apparent the bit was worn. During the following trip into the hole, an obstruction was encountered at 575 m (1887 ft). The obstruction was thought to be a loosened casing shoe, or possibly a collapsed casing. Drillers attempted to mill the obstruction, but hole conditions improved little. Petrolog was called out to run caliper, collar-locator, and cement-bond logs. The caliper log definitely determined that the casing shoe and two joints of casing had parted and fallen downhole 20 m (67 ft). The top of the parted casing was at 575 m (1887 ft). The collar-locator log determined that there was a collar at the bottom of the cemented casing looking down toward the parted section. The cement-bond log showed good bond to approximately 533 m (1750 ft), and about 70% bonding below 533 m (1750 ft).

It appears that at least three things caused the casing to part. Any one of the events would probably not have caused problems; in combination, however, the events caused the casing to part. The formations of the upper zones were semi-consolidated, and they did not place the casing shoe in indurated beds. The cement was over-retarded. The drill cuttings showed that the cement was still soft days later. Also, the poor bond identified by the cement-bond log indicated the cement bond was broken because the annular cement was soft during the drilling of the cement inside the casing. The high makeup torque on the joint that parted could have cracked the collar or sheared the lower casing threads. It is also possible that the soft cement would not hold the casing, and the rotating action of the bit inside the casing unthreaded (backed off) the casing. In either case, the soft cement could not hold the casing and allowed the casing to drop.

Attempts to mill the casing caused sidetracking around the parted casing on the low side. The hole was simultaneously enlarged by washout due to the drilling-fluid action. The large hole diameter at the top of the parted casing made entry into the casing difficult.

Prior to completion of the injection well, four joints of 25-cm (9-5/8-in.) casing with modified guide shoe were run into the hole. The casing was successfully passed through the parted 34-cm (13-3/8-in.) casing. This verified the well could be deepened and completed at a later date utilizing a 25-cm (9-5/8-in.) liner.

Lost Logging Tool -- While logging Leg A, the logging cable parted, dropping the acoustic tool to the bottom. Later, while coming up the hole with a tool, a stabilizer spring and collar were pulled loose at the liner hanger. Two fishing attempts retrieved 9 m (28 ft) of the acoustic tool. One mill and two magnet runs cleaned the hole for further drilling.

Lost Monel Drill Collar -- While building the shoulder for Leg B, the box end of the Monel collar broke. Fishing tools were ordered, and one fishing run recovered the collar at 1470 m (4831 ft): 185 m (606 ft) off the bottom.

V. INJECTION TEST

At a depth of 866 m (2840 ft), a preliminary injection test was run for 5 hours, utilizing the two rig pumps (see Figure 7). Pump One operated at 22.9 L/stroke (6.3 gal/stroke), and Pump Two delivered 9.4 L/stroke (2.6 gal/stroke) at 90% efficiency. The initial wellhead pressure was 220 kPa (32 psi). The test was run by periodically stepping up strokes to a maximum output of 932 L/sec (534 gpm). The maximum pressure recorded was 540 kPa (78 psi). The strokes were then step-reduced to zero. Pressure returned to 220 kPa (32 psi) within one hour of shut-in. The formations appeared to accept fluid more readily with time.

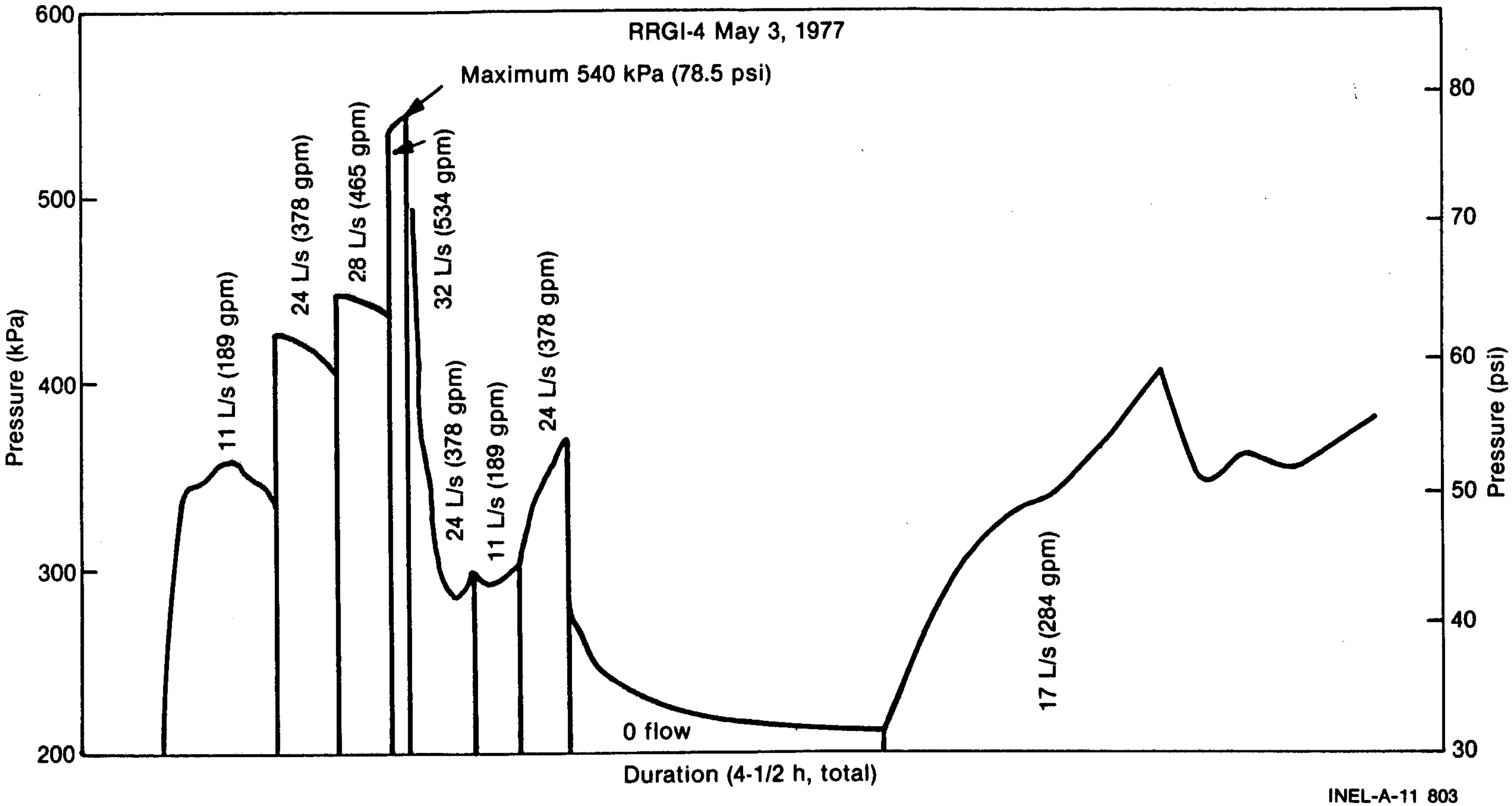

Fig. 7 Injection pump test.

APPENDIX A

DAILY DRILLING REPORTS

The following tables contain excerpts from the notes recorded in the driller's IADC "Daily Drilling Report."

TABLE A-I

DAILY DRILLING REPORTS

RRGI-4

March 31, 1977	Cellar completed.
April 3, 1977	Rat, mouse, and conductor set.
April 4, 1977	Rig on location.
April 5 to 7, 1977	Rigged up Colorado Well Service Rig #99, a Cabot 900 with 34-m (112-ft) derrick. Substructure was 4 m (14 ft) above ground level. Stabilization equipment was on location. Water line laid from RRGE-1 to location.
April 8, 1977	Spudded. Drilled 38-cm (15-in.) hole from 13 m (44 ft) to 128 m (419 ft) (Kelly Bushing) in 10 hours[a]. Center punched with 66-cm (26-in.) hole opener to start hole. Drilled with 10 16- x 6-cm (6-1/2- x 2-1/4-in.) drill collars. The 20-cm (8-in.) collars from Nevada Test Site (NTS) had not arrived. Drilled with Pump 1 20- x 41-cm (7-3/4- x 16-in.) Ideco 700-MM Pump with 15-cm (6-in.) liners at 53 strokes per minute (SPM). Pump 2 is an 18- x 36-cm (7- x 14-in.) Gardner Denver.
April 9, 1977	Drilled 66-cm (26-in.) hole from 13 m (44 ft) to 58 m (190 ft). Drill collars: 1 monel, 8 steel 20- x 8-cm (7-3/4- x 3-in.). Bit 66-cm (26-in.) Hole Opener (HO).

[a] All depths referenced to Kelly Bushing (KB) 4 m (14 ft) above ground level unless specified.

Table A-I (Cont.)

April 10, 1977	Drilled 66-cm (26-in.) hole to 125 m (410 ft) in 8 hours. Circulated 2-1/2 hours; took 2-1/2-hour trip to lay down tools and hole opener, and 11 hours to run in 51-cm (20-in.) casing with Parrish Oil tool. Had to spud and wash from 21 m (70 ft) to bottom. Probable dogleg at 21 m (70 ft).
April 11, 1977	Ran casing (2-1/2 hours). Totaled 10 joints of 51-cm (20-in.) H-40 104-kg/m (94-lb/ft) casing; welded and tacked each joint. Circulated 45 minutes to bottom: 124 m (407 ft) GL. Cemented casing.
April 12, 1977	Waited on concrete (WOC) 8 hours while installing bradenhead, 51-cm (20-in.) expansion spool, 51-cm (20-in.) single-gate BOP, and flow nipple. Nippled up for 1/2-hour pressure test. Held 2000 kPa (300 psi) for 15 minutes. Made up tools and tripped in hole. Drilled cement, shoe, and float collar. Drilled to 160 m (526 ft). Two-hour trip for plugged bit.
April 13, 1977	Drilled 31-cm (12-1/4-in.) hole to 444 m (1456 ft).
April 14, 1977	Drilled to 582 m (1908 ft). Made up Joides corebarrel system.
April 15, 1977	Made 2-hour trip in with corebarrel. Stuck tool at stabilizer at 442 m (1450 ft). Worked pipe 14 hours. Spotted with 3630 L (1,000 gal) diesel fuel. Took 8 hours to rig up Dialog; set off 2 string shots at 441 m (1448 ft). Backed off corebarrel and stabilizer. Tripped out. Went in hole with Bowen 20-cm (8-in.) jars and bumper sub. Screwed into fish. Set off jars one time. Started out with fish.
April 16, 1977	Took 4-hour trip out with fish; recovered everything. Took 8 hours to log hole with Dresser-Atlas. Mud gelled due to BHT and standing in hole. Tripped in hole, circulated, and conditioned hole. Dresser continued to log the hole.

Table A-I (Cont.)

April 17, 1977	Completed logging. Picked up corebarrel. Tripped in hole. Cored 5 m (15 ft) and recovered 1 m (3.5 ft) of core.
April 18, 1977	Opened 31-cm (12-1/4-in.) hole with 44-cm (17-1/2-in.) hole opener to 399 m (1310 ft).
April 19, 1977	Opened hole 586 m (1923 ft).
April 20, 1977	USGS attempted caliper log unsuccessfully for 6 hours. Took 12 hours to rig-up Lamb "JAM" system and run 49 joints of 34-cm (13-3/8-in.) K-55, 81-kg/m (54.5-lb/ft) casing, plus guide shoe, float collar, and DV tool. Stage cemented with 9180 L (60 bbl) water ahead, 368 sacks pozmix, 35% silica flour and 0.03% Hallad 9. Circulated 2 hours through ports and DV tool. Circulated excess cement to surface and continued to circulate with gel while WOC.
April 21, 1977	WOC 6 hours between stages. Took 2 hours to cement second stage through DV tool at 426 m (1397 ft) to surface with 1013 sacks of Poz mix with 35% silica flour. Nippled up BOP equipment.
April 22, 1977	Nippled up BOP. Installed expansion spool, master gate, adapter spool, double-gate Shaffer BOP, Grant rotating head, and flow line. Pressure-tested system for 1/2 hour at 2000 kPa (300 psi) with master gate valve closed. Pressure-tested system after drilling DV tool with Hydril closed at 2000 kPa (300 psi) for 15 minutes. Drilled with water to 617 m (2025 ft).
April 23, 1977	Drilled 31-cm (12-1/4-in.) to 647 m (2124 ft). Tripped in with corebarrel. Hit obstruction at 579 m (1901 ft). Worked bit through while rotating. There was no drag on pull back. Worked through several times with no improvement. Tripped out (corebit still in good condition). Ran in hole and worked through tight spot. No improvement. Pipe torqued up and backed off. Tripped out to check. Backed off 15 stands (30 joints) down. Tripped in and screwed into tool. Bit lodged at 579 m (1901 ft). Tripped out. Tripped in and hit junk at 579 m (1901 ft). Attempted unsuccessfully to work through it.

Table A-I (Cont.)

April 24, 1977	Tripped out. Waited on milling tools. Picked up flat-bottom mill and tripped in hole. Hit junk at 579 m (1901 ft). Milled 5 hours: 579 to 582 m (1901 to 1909 ft). Worked back and forth. Kept hanging up at 579 m (1901 ft). Tripped out. Picked up tapered mill and stabilizer. Hit junk at 579 m (1901 ft). Drilled and worked tapered mill to 593 m (1946 ft) until mill would go without rotating. Well was flowing.
April 25, 1977	Tripped out with tapered mill and tripped in with flat-bottom mill, junk sub, and stabilizer. Milled from 579 to 582 m (1901 to 1909 ft). Tripped out and layed down tools. Rigged up to run electric log (EG&G). Logged two hours. Ran in hole with tapered mill and stabilizer. Hit junk at 579 m (1901 ft). Worked through to fill at 629 m (2065 ft). Washed out fill to 647 m (2124 ft) and circulated to bottom. Called out petrolog to run collar log, cement bond, and caliper log in order to diagnose situation.
April 26, 1977	Tripped out with tapered mill. Petrolog ran logs 8 hours. Ran caliper, collar locater, and cement-bond logs. Determined bottom 2 joints of 34-cm (13-3/8-in.) casing had parted and had fallen down hole with male end looking up. Top of fish was at 579 m (1901 ft). Bottom of cemented casing was at 559 m (1835 ft). Collar was looking down. Ran 6-hour temperature log with EG&G logging unit. Temperature was 113.5°C (236.5°F) at top of parted casing. Well was flashing. Installed Hughes bit guide and tripped in hole to 579 m (1901 ft). Worked bit through top of fish. Found no fill and very little junk. Drilled to 861 m (2235 ft).
April 27, 1977	Drilled to 745 m (2445 ft). Lost all circulation at 745 m (2445 ft). This came back about 50%. Tripped out, picked up corebarrel. Could not tag casing at 579 m (1901 ft). Tripped out and picked up bit. Ran in hole to 579 m (1901 ft) and attempted unsuccessfully to work through 34-cm (13-3/8-in.) casing; kept falling off side of 34-cm (13-3/8-in.) casing.

Table A-I (Cont.)

April 28, 1977	Could not get inside 34-cm (13-3/8-in.) casing at 579 m (1901 ft). Picked up bit, stabilizer, 2 drill collars, stabilizer, and 6 drill collars, and tripped into hole. Failed to work through casing at 579 m (1901 ft); tripped out. Well was flashing. Pumped cool water down hole. Tripped into hole with tapered mill. Spent 2 hours trying to work through casing at 579 m (1901 ft). Tripped out. Waited on spear for 34-cm (13-3/8-in.) casing.
April 29, 1977	Made up tools. Started in hole. Slips were too large. Broke down spear, waited on smaller slips. Dressed spear in 1 hour. Tripped in hole with bent 9-cm (3-1/2-in.) drill-pipe stinger, 4-m (13-ft) spear, 2 drill collars, jars and 6 drill collars. Spent 2 hours working on spear in 34-cm (13-3/8-in.) casing at 579 m (1901 ft). Could not set spear, so tripped out. One spring on setting device had broken off. Replaced spring. Tripped in hole. Worked spear in 34-cm (13-3/8-in.) casing. Worked pipe and set off jars. Could not move fish. Tripped out of hole.
April 30, 1977	Picked up bit with jars and ran into hole to 579 m (1901 ft). Worked through 34-cm (13-3/8-in.) casing and to 728 m (2390 ft). Cleaned fill from bottom and drilled to 864 m (2834 ft). Tried 8 hours to flow well for maximum temperature buildup. No flow. Ran temperature survey: 82°C (180°F) maximum at 518 m (1700 ft).
May 1, 1977	Tripped out, picked up corebarrel, shock sub, and collars, and tripped in hole. Worked through 34-cm (13-3/8-in.) casing at 579 m (1901 ft). Went to 855 m (2806 ft). Cleaned out fill to TD and cored 6 m (20 ft). Tripped out and emptied corebarrel. Recovered 7 m (13 ft). Tripped in to 579 m (1901 ft). Attempted to work bit through. Tripped out. Tripped in with shock sub on bottom of collars. Attempted to work through at 579 m (1901 ft). Tripped out.

Table A-I (Cont.)

May 2, 1977	Picked up tapered mill, float sub, and bent joint drill pipe. Tripped to 579 m (1901 ft). Attempted to work through casing. Got through with Kelly on, but had to pull back for connection and could not get back in. Tripped out. Ran temperature log.
May 3, 1977	Ran 5-hour step injection test using both rig pumps. Wellhead pressure reached 345 kPa (50 psi) at 30 SPM and 11.4 L/sec (189 gpm), and reached maximum of 538 kPa (78 psi) at 120 SPM and 32 L/sec (534 gpm). Picked up four joints of 24-cm (9-5/8-in.) casing with modified shoe and ran to 579 m (1901 ft). Worked casing through 34-cm (13-3/8-in.) casing and down to 595 m (1952 ft). Repaired wireline and tool on logging unit. Ran temperature log inside pipe. Maximum temperature was 122°C (252°F) at 823 m (2700 ft).
May 4, 1977	Ran 8-hour injection test and cooled down the well. Tripped out with drill pipe and 4 joints of casing with modified shoe. Casing run was made to verify that the well could be completed later as a production well. Broke down core-barrel. Layed down drill pipe and drill collars. Closed master gate and rigged down.

TABLE A-II

DAILY DRILLING REPORTS, RRGI-4

September 21, 1978	Completed rig up over RRGI-4. Rigged up 20-cm (8-in.) flow line. Redrilled the rat and mouse holes. Picked up bit and drill collars.
September 22, 1978	Picked up drill pipe and drilled by parted casing to 607 m (1990 ft). Tripped out to change bit.
September 23, 1978	Tripped into hole and drilled to 684 m (2245 ft).
September 24, 1978	Tripped out to change bits and drilled to 834 m (2737 ft). Drilling quartz and siltstone.
September 25, 1978	Tripped out of hole for bit change. Changed Grant rotating head rubber and drilled to 927 m (3040 ft).
September 26, 1978	Drilled to 1000 m (3280 ft). Tripped out of hole for bit change. Ran survey. On each trip into hole it became easier to drop past the partial casing.
September 27, 1978	Drilled to 1056 m (3464 ft) in siltstone. Circulated to clean hole for logging. Tripped out of hole and prepared for loggers.
September 28, 1978	Logged well. Injected 48 L/sec (800 gpm) into the well at 3500 kPa (500 psi) while the temperature-logging tool was in the well.
September 29, 1978	Completed logging hole and waited for Otis casing hanger.
September 30, 1978	Waited for Otis casing hanger.
October 1, 1978	Rigged up and ran 24-cm (9-5/8 in.) casing. Bottom of casing set at 1054 m (3457 ft). Casing hanger set at 461 m (1512 ft). Mixed 1450 sacks of cement. Completed cement job, but lost returns for 20 minutes. Layed down 20-cm (8-in.) collars and picked up 15-cm (6-in.) collars.
October 2, 1978	Waited on cement, then drilled out cement from 415 m (1360 ft) to 461 m (1512 ft).
October 3, 1978	Cement bond log indicated no cement from casing hanger down to 560 m (1837 ft). Rigged up to cement down through casing hanger. Waited on cement.
October 4, 1978	Mixed 200 sacks cement and squeezed cement down through casing hanger. Pulled out packer.

TABLE A-II (cont.)

October 5, 1978	Ran cement-bond log. Measured no bond 558 to 523 m (1830 to 1715 ft), 20% bond 523 to 461 m (1715 to 1512 ft). Ran bit in to see if hole was clear. Pressure-tested casing to 11,700 kPa (1700 psi) with Halliburton rig, and found no leaks. Idaho Water Resource representative elected not to observe test.
October 6, 1978	Drilled through shoe to 1082 m (3550 ft). Tripped to prepare for whipstocking. Rigged up turbodrill and tripped into hole.
October 7, 1978	Drilled and ran surveys to 1098 m (3620 ft). Tripped out to remove turbodrill. Tripped back into hole.
October 8, 1978	Drilled and ran surveys alternately to 1175 m (3853 ft). Circulated and tripped out of hole. Deviation was about 10-1/2 degrees in a N5W direction.
October 9, 1978	Reamed to bottom and drilled to 1221 m (4006 ft) through quartz and siltstone.
October 10, 1978	Drilled to 1229 m (4032 ft). Tripped out to change out bottom hole reamer and bit. Drilled on to 1323 m (4340 ft).
October 11, 1978	Drilled and took surveys to 1405 m (4608 ft). Tripped for bit change and drilled to 1443 m (4667 ft).
October 12, 1978	Drilled to 1489 m (4886 ft). Encountered quartz. Deviation at 1446 m (4746 ft) was 10 degrees in a N10W direction.
October 13, 1978	Drilled to 1508 m (4947 ft). Tripped for bit change, reamed back to bottom.
October 14, 1978	Drilled through quartz to 1530 m (5020 ft).
October 15, 1978	Drilled to 1545 m (5069 ft). Hung up on a key seat coming out of hole at 1148 m (3767 ft). Worked loose and tripped out. Picked up Dresser 6-point reamer. Reamed 1128 to 1167 m (3700 to 3830 ft) with key seat wiper. Reamed on down hole.
October 16, 1978	Reamed on to bottom of hole. Drilled ahead to 1562 m (5124 ft).
October 17, 1978	Drilled to 1566 m (5138 ft). Tripped for bit change and drilled to 1574 m (5165 ft). Encountered quartz monzonite.

TABLE A-II (cont.)

October 18, 1978	Drilled ahead to 1589 m (5212 ft). Took survey and tripped out for bit change. Reamed bottom part of hole, but got stuck 2 m (5 ft) off bottom.
October 19, 1978	Worked loose but could not get below stuck point. Circulated and waited on logging truck. Rigged up loggers.
October 20, 1978	Logged well. Logger lost 10-cm (4-in.) spring and steel sleave in hole. Lost acoustic logging tool in hole.
October 21, 1978	Completed logging. Fished for acoustical tool, but recovered only 2.4 m (8 ft) of the tool.
October 22, 1978	Went in with overshot but hit hanger. Tripped out. Overshot was split. Changed overshot and fished with no results. Tripped in again with another overshot and recovered 6 m (20 ft).
October 23, 1978	Tripped in and fished with no further results. Repair work done on rig.
October 24, 1978	Completed rig repairs. Completed trip in hole.
October 25, 1978	Milled 8 hours on junk. Tripped back in with magnet and recovered 14 kg (30 lb) junk.
October 26, 1978	Made one more magnet run. Tripped in with new bit. No junk was encountered. Drilled to 1604 m (5263 ft).
October 27, 1978	Drilled to 1610 m (5283 ft) and tripped for bit change. Drilled on to 1629 m (5343 ft).
October 28, 1978	Drilled to 1654 m (5427 ft). Circulated hole in preparation for logging. Tripped out of hole.
October 29, 1978	Logged hole. Ran in hole and started to build shoulder for second leg.
October 30, 1978	Drilled 21 m (68 ft) on second leg shoulder. Tripped out, but left monel drill collar in hole. Flow-tested while awaiting fishing tools.
October 31, 1978	Made two fishing runs, recovering fish on second run. Tripped back into hole.
November 1, 1978	Drilled kickoff shoulder to 1106 m (3630 ft). Tripped out of hole.

November 2, 1978	Picked up turbodrill and drilled to 1127 m (3697 ft). Tripped out of hole for bit change.
November 3, 1978	Reamed hole to TD and tripped for bit change. Drilled to 1210 m (3970 ft).
November 4, 1978	Drilled to 1222 m (4009 ft). Tripped to lay down turbodrill. Reamed back to 1222 m (4090 ft) with a 3-point reamer string key-seat wiper.
November 5, 1978	Drilled and ran surveys to 1409 m (4624 ft).
November 6, 1978	Drilled to 1414 m (4640 ft). Tripped out and picked up core barrel. Cored 5 m (15 ft) and recovered 3 m (9 ft). Tripped back in to cut second core.
November 7, 1978	Cored 5 m (15 ft) of hole and recovered 2 m (7 ft) of core. Reamed core hole and drilled to 1454 m (4770 ft).
November 8, 1978	Drilled to 1473 m (4833 ft). Tripped out for bit change. Reamed to bottom and drilled to 1474 m (4837 ft).
November 9, 1978	Drilled to 1503 m (4930 ft) and tripped out for bit and reamer change.
November 10, 1978	Drilled on to 1521 m (4991 ft).
November 11, 1978	Drilled to 1541 m (5056 ft). Reamed tight section of hole 1158 to 1280 m (3800 to 4200 ft). Tripped out for bit change.
November 12, 1978	Drilled to 1559 m (5115 ft). Circulated hole for logging. Tripped out of hole. Hole was still tight around 1173 m (3850 ft).
November 13, 1978	Waited on loggers. Began running logs late.
November 14, 1978	Completed logging. Picked up turbodrill, monel collar and 2-degree kick sub. Tried to orient tool to get back in Leg A, but failed to get in. Began laying down drill pipe.
November 15, 1978	Completed laying down drill pipe. Started rig down. Released rig.

APPENDIX B

BIT RECORD

The following tables provide a performance record for each of the bits used to drill Well Four. This information was also obtained from the IADC "Daily Drilling Report."

TABLE B-I

BIT RECORD, RRGI-4

Bit	Make	Size [cm (in.)]	Type	Jets	Serial Number	Depth Out [m (ft)]	Total Footage [m (ft)]	Hours	Weight [x10³ kg (x10³ lb)]	RPM	Pump Pres. [kPa (Psi)]	SPM	Dull Condition T/B/G	Remarks
1	Security	38 (15)	S3J	15/15/15	687010	128 (419)	114 (375)	10	1/7 (3/15)	70	2100 (300)	53		Start RRGI-4
2A	Smith	31 (12 1/4)	U2J	-	CD120	128 (419)	114 (375)	14	1 (2)	70	2100 (300)	48/90		With 66 cm (26 in) hole opener
2B	Smith	31 (12 1/4)	U2J	14/14/14	950EW	334 (1097)	225 (739)	14	7 (15)	75	2800 (400)	54		With 66 cm (26 in) hole opener
3	Smith	31 (12 1/4)	F2	14/14/15	363HW	582 (1908)	247 (811)	17 1/2	5/7 (10/15)	70	3100 (450)	54		
-(RR)	Smith	31 (12 1/4)	U2J	14/14/15	950EW	586 (1923)	458 (1504)	36 1/2	7 (15)	90	3500 (500)	56		Reaming to 44 cm (17 1/2 in)
4(RR)	Smith	31 (12 1/4)	U2J	14/14/15	CD120	647 (2124)	61 (201)	11	4/7 (8/15)	90	1400/3500 (200/500)	56	7/6/8	
5	Smith	31 (12 1/4)	U2J	14/14/15	AJ567	- -	0 (0)	1	- -	-	- -	-	6/4/8	
6	Smith	31 (12 1/4)	U2J	14/14/15	AJ591	- -	- -	-	- -	-	- -	-	-	
7	Smith	31 (12 1/4)	SVJ	14/14/15	1914DR	745 (2445)	98 (321)	8	7 (15)	90	3500 (500)	56		
8	Smith	31 (12 1/4)	SVJ	14/14/15	062HC	864 (2834)	119 (389)	9	5/7 (10/15)	100	4100 (600)	56		
9	Smith	31 (12 1/4)	SVJ	14/14/15	-	- -	(0)	-	5 (10)	45/60	2500 (350)	54		

TABLE B-II

BIT RECORD, RRGP-4

Bit	Make	Size [cm (in.)]	Type	Jets	Serial Number	Depth Out [m (ft)]	Total Footage [m (ft)]	Hours	Weight [x10³ kg (x10³ lb)]	RPM	Pump Pres. [kPa (psi)]	SPM	Dull Condition T/B/G	Remarks
1	Smith	31 (12 1/4)	SVH	Open	592KN	607 (1990)	16 (54)	13 1/2	5 (10)	50	5500 (800)	50		Start RRGP-4
2	Smith	31 (12 1/4)	SVH	Open	963FA	684 (2245)	78 (255)	20 1/2	5 (10)	50	5500 (800)	50		
3	Smith	31 (12 1/4)	SVH	Open	279FB	863 (2832)	179 (587)	26	7 (15)	60	5500 (800)	50	8/4/ 1/4	
4	Smith	31 (12 1/4)	SVHJ	Open	638FJ	1000 (3280)	130 (448)	23	7 (15)	60	5500 (800)	50		
5	Hughes	31 (12 1/4)	OWVJ	Open	FF880	1056 (3464)	55 (184)	18	7/9 (15/20)	60	5500 (800)	50		
6	Hughes	22 (8 3/4)	JD8	Open	DM855	1075 (3526)	19 (62)	2 1/2	9 (20)	60	3500 (500)	65		
7	Reed	22 (8 3/4)	F34J	Open	604953	1098 (3602)	23 (76)	6	2/4 (4/8)	-	7900 (1150)	76		Turbodrill
8	Reed	22 (8 3/4)	F31GJ	Open	837588	1174 (3853)	77 (251)	10	2/3 (5/7)	-	6600 (950)	62		Turbodrill
9	Reed	22 (8 3/4)	F34J	Open	604621	1229 (4032)	55 (179)	18 1/2	4/8 (4/18)	60	4100 (600)	76		
10	Security	22 (8 3/4)	M84F	Open	829016	1405 (4608)	176 (576)	23	8 (18)	70	5500 (800)	65		
11	Security	22 (8 3/4)	M84F	Open	829066	1508 (4947)	103 (339)	34	11 (24)	60	5500 (800)	76		
12	Hughes	22 (8 3/4)	J77	Open	FL260	1545 (5069)	37 (122)	22	12 (26)	60	3500 (500)	68		
13	Security	22 (8 3/4)	H-100-F	Open	712017	1566 (5138)	21 (69)	19	12 (26)	65	2800/5500 (400/800)	78		
14	Hughes	22 (8 3/4)	J77	Open	FL255	1589 (5212)	23 (74)	20 1/2	7/11 (15/25)	50	5500 (800)	76		
15	Security	22 (8 3/4)	M84F	Open	815783	-	-	-	-	-	6900 (1000)	75		
16(RR)	Hughes	22 (8 3/4)	J77	Open	-	1610 (5283)	22 (71)	19	11 (25)	60	5500 (800)	65		

TABLE B-II (Cont.)

Bits	Make	Size [cm (in.)]	Type	Jets	Number Serial	Depth Out [m (ft)]	Total Footage [m (ft)]	Hours	Weight [x10³ kg (x10³ lb)]	RPM	Pump Pres. [kPa (psi)]	SPM	Dull Condition T/B/G	Remarks
17	Security	22 (8 3/4)	H-100-F	Open	774156	1654 (5427)	46 (151)	25	11 (25)	65	6200 (900)	65		
18	Hughes	22 (8 3/4)	XDV	Open	EN186	1104 (3622)	20 (67)	12	1 (2)	120	6900 (1000)	75		Bldg. Shoulder for 4B
19 (RR)	Reed	22 (8 3/4)	-	Open	604621	- -	- -	-	- -	-	- -	-		Bldg. Shoulder for 4B
20	Reed	22 (8 3/4)	F34J	Open	229288	1126 (3696)	12 (41)	10	1 (2)	-	7900 (1150)	72		Turbodrill
21	Reed	22 (8 3/4)	F31G	Open	837584	1127 (3697)	0 (1)	2 1/2	1 (2)	-	7900 (1150)	72		Reaming
22	Reed	22 (8 3/4)	F31G	Open	837583	1222 (4009)	95 (312)	10	3 (6)	-	8300 (1200)	72		Turbodrill
23	Security	22 (8 3/4)	S88	Open	711010	1414 (4640)	192 (631)	31	3 (6)	70	4800/5500 (700/800)	70		
24	Hycalog	20 (7 7/8)	CMHIP	-	17479	1419 (4656)	5 (16)	2	8 (18)	75	1700 (250)	24		Coring
25	Hycalog	20 (7 7/8)	PC20P	-	17184	1424 (4671)	5 (15)	1	8 (18)	80	1200 (175)	22		Coring
26	Hughes	22 (8 3/4)	J77	Open	F1214	1473 (4833)	50 (163)	20 1/2	10 (23)	55	4100 (600)	70		
27	Hughes	22 (8 3/4)	J77	Open	FL257	1503 (4930)	30 (97)	22 1/2	10 (23)	55	4100 (600)	70		
28	Security	22 (8 3/4)	H-100-F	Open	697630	1541 (5056)	38 (126)	25	10 (23)	58	2800 (400)	72		
29	Security	22 (8 3/4)	H-100-F	Open	680202	1559 (5115)	18 (59)	16 1/2	10 (23)	56	4100 (600)	72		

APPENDIX C

DIRECTIONAL DRILLING SURVEY SUMMARY

The following tables and figure contain excerpts from the Eastman Whipstock Multiple-Shot Survey records for both legs of well RRGP-4.

TABLE C-I

DIRECTIONAL DRILLING SURVEY SUMMARY, RRGP-4A

Measured[a] Depth [m (ft)]	Observed Angle (degrees)	Observed Direction (degrees)	Rectangular Coordinates [m (ft)]			
			North	South	East	West
1055 (3460)	3	N 26 E	0.35 (1.14)	-	0.21 (0.69)	-
1064 (3490)	3	N 65 W	0.88 (2.89)	-	0.05 (0.15)	-
1074 (3523)	3-1/2	N 70 W	1.10 (3.61)	-	-	0.48 (1.58)
1084 (3555)	4-1/4	N 60 W	1.38 (4.52)	-	-	1.08 (3.54)
1096 (3595)	4-1/2	N 46 W	1.94 (6.36)	-	-	1.83 (5.99)
1105 (3625)	4-1/2	N 25 W	2.52 (8.28)	-	-	2.24 (7.36)
1115 (3657)	5	N 5 W	3.30 (10.84)	-	-	2.45 (8.05)
1124 (3687)	6	N 10 E	4.18 (13.71)	-	-	2.47 (8.10)
1134 (3720)	7-1/4	N 8 E	5.32 (17.47)	-	-	2.25 (7.38)
1143 (3751)	8	N 1 E	6.57 (21.57)	-	-	2.20 (7.22)
1153 (3782)	9	N 5 W	7.97 (26.15)	-	-	2.21 (7.26)
1162 (3813)	10	N 8 W	9.52 (31.23)	-	-	2.44 (8.00)
1176 (3857)	11	N 15 W	11.91 (39.09)	-	-	2.93 (9.60)
1204 (3949)	10-1/2	N 15 W	16.97 (55.67)	-	-	4.28 (14.04)
1241 (4073)	10	N 13 W	23.49 (77.08)	-	-	5.91 (19.38)
1283 (4208)	10	N 13 W	30.46 (99.92)	-	-	7.51 (24.65)
1317 (4322)	9	N 13 W	36.04 (118.25)	-	-	8.80 (28.88)
1364 (4476)	10	N 13 W	43.59 (143.02)	-	-	10.55 (34.60)

[a] The leg is assumed to be vertical from a depth of 0 to 1055 m (0 to 3460 ft).

Table C-I (Cont.)

Measured[a] Depth [m(ft)]	Observed Angle (degrees)	Observed Direction (degrees)	Rectangular Coordinates [m (ft)] North	South	East	West
1412 (4632)	9-1/2	N 12 W	51.45 (168.81)	-	-	12.29 (40.32)
1440 (4726)	10	N 10 W	56.22 (184.44)	-	-	13.22 (43.36)
1497 (4913)	10	N 11 W	65.95 (216.37)	-	-	15.02 (49.28)
1575 (5167)	12	N 10 W	80.47 (264.02)	-	-	17.71 (58.11)

[a] The leg is assumed to be vertical from a depth of 0 to 1055 m (0 to 3460 ft).

TABLE C-II

DIRECTIONAL DRILLING SURVEY SUMMARY, RRGP-4B

Measured[a] Depth [m(ft)]	Observed Angle (degrees)	Observed Direction (degrees)	Rectangular Coordinates [m (ft)] North	South	East	West
1055 (3460)	3	N 26 E	0.43 (1.41)	-	0.21 (0.69)	-
1064 (3490)	3	N 65 W	0.88 (2.89)	-	0.05 (0.15)	-
1084 (3555)	4-1/4	N 60 W	1.46 (4.79)	-	-	1.04 (3.40)
1092 (3582)	4	N 58 W	1.76 (5.79)	-	-	1.54 (5.06)
1098 (3603)	4	N 35 W	2.26 (7.41)	-	-	1.98 (6.49)
1111 (3646)	4-1/2	N 37 W	2.86 (9.39)	-	-	2.42 (7.93)
1121 (3677)	4	N 19 W	3.48 (11.42)	-	-	2.75 (9.01)
1130 (3706)	4	N 1 E	4.09 (13.42)	-	-	2.84 (9.33)
1138 (3735)	4	N 20 E	4.70 (15.41)	-	-	2.74 (8.98)
1147 (3764)	3-1/4	N 70 E	5.86 (19.24)	-	-	1.34 (4.41)
1174 (3853)	6-1/4	N 65 E	6.21 (20.37)	-	-	0.52 (1.69)
1193 (3913)	8-3/4	N 63 E	7.25 (23.80)	-	1.63 (5.35)	-
1211 (3973)	11	N 70 E	8.50 (2790)	-	4.51 (14.79)	-
1262 (4142)	11	N 71 E	11.30 (37.06)	-	13.93 (45.71)	-
1328 (4356)	11	N 82 E	13.56 (44.50)	-	26.17 (85.86)	-
1404 (4605)	10-1/4	N 80 E	15.75 (51.68)	-	39.99 (131.21)	-
1441 (4728)	10-1/2	N 82 E	16.81 (55.15)	-	46.66 (153.08)	-
1460 (4790)	10-1/2	N 80 E	17.35 (56.92)	-	50.06 (164.24)	-
1535 (5036)	14	N 70 E	2150 (70.54)	-	65.55 (215.07)	-

[a] The leg is assumed to be vertical from a depth of 0 to 1055 m (0 to 3460 ft).

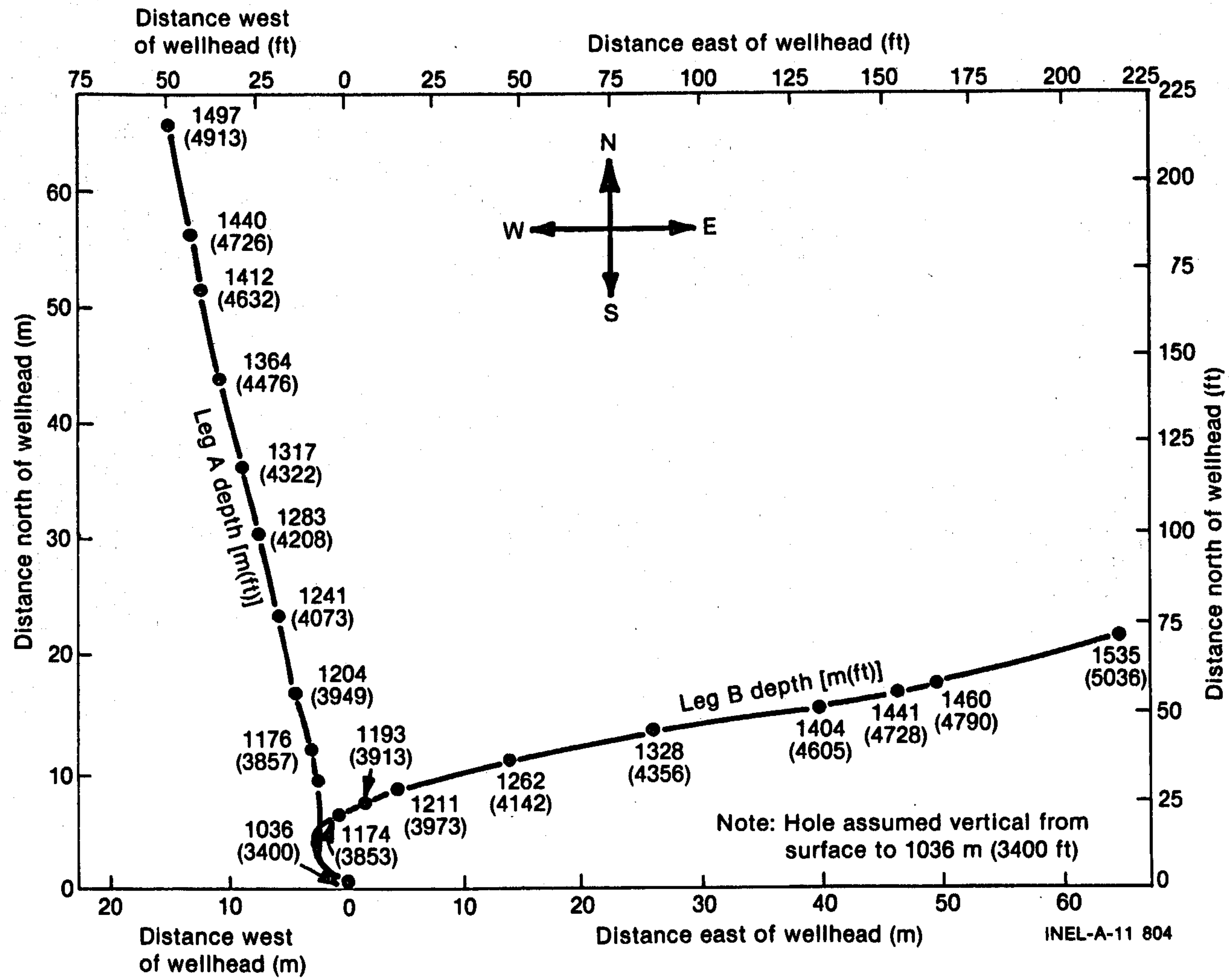

Fig. C-1 Directional drilling survey summary.

APPENDIX D

CASING SUMMARY

The following tables contain excerpts from notes recorded in the drilling superintendent's casing record notebook.

TABLE D-I

INTERMEDIATE CASING SUMMARY

Joint[a]	Length [m (ft)]	Accumulated Length [m (ft)]	Remarks
1	11.73 (38.50)	11.73 (38.50)	Centralizer
2	11.75 (38.54)	23.48 (77.04)	
3	11.38 (37.32)	34.86 (114.36)	
4	12.28 (40.30)	47.14 (154.66)	
5	11.73 (38.50)	58.87 (193.16)	Centralizer
6	12.14 (39.84)	71.01 (233.00)	
7	11.59 (38.03)	82.60 (271.03)	
8	11.50 (37.72)	94.11 (308.75)	Centralizer
9	12.14 (39.84)	106.25 (348.59)	
10	11.50 (37.90)	117.80 (386.49)	
11	11.29 (37.03)	129.09 (423.52)	Centralizer
12	11.99 (39.35)	141.08 (462.87)	Centralizer
13	11.58 (38.00)	152.66 (500.87)	
14	12.09 (39.67)	164.75 (540.54)	Centralizer
15	12.49 (40.99)	177.24 (581.53)	
16	11.81 (38.75)	189.05 (620.28)	
17	11.11 (36.46)	200.16 (656.74)	Centralizer
18	12.30 (40.35)	212.47 (697.09)	
19	11.83 (38.80)	224.30 (735.89)	
20	11.70 (38.38)	236.00 (774.27)	Centralizer
21	12.07 (39.59)	248.07 (813.86)	
22	12.13 (39.80)	260.20 (853.66)	
23	11.70 (38.38)	271.90 (892.04)	Centralizer
24	11.88 (38.98)	283.78 (931.02)	
25	12.05 (39.53)	295.83 (970.55)	
26	12.06 (39.57)	307.88 (1010.12)	Centralizer
27	12.06 (37.57)	319.34 (1047.69)	
28	12.16 (39.88)	331.49 (1087.57)	
29	12.25 (40.20)	343.74 (1127.77)	Centralizer
30	11.54 (37.85)	355.28 (1165.62)	
31	11.63 (38.15)	366.91 (1203.77)	
32	11.17 (36.66)	378.08 (1240.43)	Centralizer
33	12.15 (39.85)	390.23 (1280.28)	
34	11.83 (38.80)	402.06 (1319.08)	
35	11.66 (38.25)	413.72 (1357.33)	Centralizer
36	11.46 (37.60)	425.18 (1394.93)	
37	11.80 (38.70)	436.98 (1433.63)	
38	11.96 (39.25)	448.94 (1472.88)	Centralizer
39	12.59 (41.30)	461.53 (1514.18)	
40	12.36 (40.55)	473.89 (1554.73)	
41	11.95 (39.22)	485.84 (1593.95)	Centralizer
42	12.37 (40.58)	498.21 (1634.53)	
43	12.49 (40.97)	510.70 (1675.50)	
44	12.72 (41.73)	523.41 (1717.23)	Centralizer
45	11.96 (39.23)	535.37 (1756.46)	
46	12.76 (41.85)	548.13 (1798.31)	
47	12.70 (41.68)	560.83 (1839.99)	Centralizer
48	12.32 (40.43)	573.15 (1880.42)	
49	12.57 (41.23)	585.72 (1921.65)	

[a] All casing was 34 cm (13-3/8 in.), K-55, ST&C, 81 kg/m (54.5 lb/ft), Range-3.

TABLE D-II

PRODUCTION CASING SUMMARY

Joint[a]	Length [m (ft)]	Accumulated Length [m (ft)]
1	12.08 (39.64)	12.08 (39.64)
2	12.09 (39.65)	24.17 (79.29)
3	12.29 (40.32)	36.46 (119.61)
4	12.64 (41.47)	49.10 (161.08)
5	12.64 (41.46)	61.73 (202.54)
6	12.66 (41.54)	74.40 (244.08)
7	12.79 (41.96)	87.18 (286.04)
8	12.79 (41.97)	99.98 (328.01)
9	12.36 (40.54)	112.33 (368.55)
10	12.73 (41.77)	125.07 (410.32)
11	12.49 (40.97)	137.55 (451.29)
12	12.26 (40.22)	149.81 (491.51)
13	11.99 (39.33)	161.80 (530.84)
14	12.77 (41.90)	174.57 (572.74)
15	11.71 (38.42)	186.28 (611.16)
16	11.29 (37.05)	197.57 (648.21)
17	12.12 (39.76)	209.69 (687.97)
18	12.73 (41.78)	222.43 (729.75)
19	11.84 (38.86)	234.27 (768.61)
20	12.90 (42.33)	247.17 (810.94)
21	11.76 (38.59)	258.94 (849.53)
22	11.76 (38.58)	270.70 (888.11)
23	12.48 (40.96)	283.18 (929.07)
24	12.80 (42.01)	295.99 (971.08)
25	12.13 (39.80)	308.12 (1010.88)
26	12.20 (40.02)	320.31 (1050.90)
27	12.69 (41.62)	333.00 (1092.52)
28	12.57 (41.24)	345.57 (1133.76)
29	11.48 (37.65)	357.05 (1171.41)
30	11.95 (39.22)	369.00 (1210.63)
31	10.71 (35.14)	379.71 (1245.77)
32	12.13 (39.81)	391.84 (1285.58)
33	11.49 (37.71)	403.34 (1323.29)
34	12.36 (40.56)	417.23 (1368.85)
35	12.91 (42.35)	428.61 (1406.20)
36	13.08 (42.90)	441.69 (1449.10)
37	10.71 (35.14)	452.40 (1484.24)
38	12.70 (41.67)	465.10 (1525.91)
39	12.65 (41.49)	477.74 (1567.40)
40	12.49 (40.96)	490.23 (1608.36)
41	12.49 (40.97)	502.72 (1649.33)
42	12.30 (40.34)	515.01 (1689.67)
43	12.52 (41.08)	527.53 (1730.75)
44	13.02 (42.71)	540.55 (1773.46)
45	12.25 (40.20)	552.80 (1813.66)
46	12.48 (40.95)	565.29 (1854.61)
47	12.20 (40.04)	577.49 (1894.65)
48	12.32 (40.43)	589.81 (1935.08)

[a]All casing was 24 cm (9-5/8 in.), K-55, Buttress Thread, 54 kg/m (36 lb/ft), Range-3.

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