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EXTENSIVE CORING IN THE DEEP HOT GEOTHERMAL WELLS

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ABSTRACT

Recent scientific projects have required extensive intermittent coring in the deep, hot geothermal areas. Two projects are the Salton Sea Scientific Drilling Project (SSSDP) at the Southeastern edge of the Hot Dry Rock Project (HDR), under development in North Central New Mexico at Fenton Hill west of Los Alamos, New Mexico. This coring in full size well bores has demonstrated that coring under the conditions which exist in geothermal formations are extremely difficult, time consuming and costly. The coring techniques applied in these projects use the best available technology from the petroleum industry and some newly improved developments. Efforts to improve recovery and efficiency were made by varying coring methods by changing core head types and sizes, barrel type and catcher types along with operational changes of rotary speeds, weight on core head and circulation rates. Primary problems limiting the coring operations were core "jamming" in the barrel and in the catcher and slow penetration rates.

INTRODUCTION

The Salton Sea Scientific Drilling Project (SSSDP) was funded by various government agencies as part of the national program of Continental Scientific Drilling. The general site was selected in one of the largest, hottest and most saline geothermal fields in the world.*1

The primary purpose of the well was to obtain geologic data for scientific analyses of the thermal regimes, minerology and fluids. The data required from the well included coring of 10 to 15% of the well depth, extensive geophysical logging, cutting sample collection and flow tests designed to provide pristine fluid samples from flow zones.

* References are at the end of text.

The extensive data collected (and being collected) on the well together with the analyses of the physical, chemical and petrophysical nature of the formations will develop one of the most extensive and unique data bases to further analyze the drilling and coring mechanics in the geothermal environment.

Drilling operations commenced October 24, 1986 and were completed on March 18, 1986 after drilling to a depth of 10,564 feet. Much of the data is in the process of being analyzed and the some of the information contained herein is preliminary.

The coring operations consumed a major portion of the time and the funds available for the project. Intermittent interval coring of a production size geothermal wellbore diameter was undertaken for many reasons. One of the primary reasons for the large wellbore was to satisfy the production testing requirements. In addition, continuous coring methods were as yet unproven in this type of the complex geologic environment, the anticipated temperature regime and in formations containing highly corrosive geothermal fluids. Limited conventional coring had been successfully employed in nearby areas at relatively shallower depths.

The HDR project located in Northern New Mexico about 45 miles west of Los Alamos, operated under the direction of Los Alamos National Laboratory, required the re-drilling of a directional well (EE-3) during the summer of 1985. Several previous intermittent coring operations had been undertaken in late 1979. That information is contained in reference 2. Cores were desired in the re-drilled EE-3A to evaluate the physical, chemical and geologic nature of the HDR reservoir rock. During this recent coring, improvements in equipment and techniques were attempted. Also, scribe catchers and directional surveys were taken in an effort to orient two of the cores.

No attempt is yet made to correlate the coring and rock properties in either of the wells. The general geologic characteristics of the cored zones are described here. Later, after a more complete determination of the petrophysical properties of the formations have been done, a more thorough analysis of the coring can be done.

A summary of the coring results are given in Tables 1 and 2. The following describes the coring equipment and operations on both holes.

DESCRIPTION OF THE BOREHOLES

The SSSDP coring was done in three different diameter holes. In the upper section, the drilled hole size was 17 1/2" from 1032' to 3500' and 12 1/4" from 3500' to 6000' (Note that unless specified all depths refer to kelly bushing which was 28.5' above ground level which is about 200' subsea). All coring runs in these two holes were made with a 9 7/8" core head which cut a 5 1/4" core. The 17 1/2" drill bits were primarily mill tooth and the 12 1/4" were tungsten carbide journal bearing type. From 6000' to 10,475' the hole size was 8 1/2" and all cores except No. 34 (Table 2) were all made with an 8 1/8" core head which cut a 4" diameter core. Core No. 34 was cut with a 7 5/8" corehead which cut a 3 1/2" core.

The HDR hole EE-3A was 8 1/2" below a milled out section of 47 lb/ft 9 5/8" casing. Primarily, drilling was with tri-cone tungsten carbide, nonsealed, air circulation bit with the air holes plugged. In addition, these bits had wear pad build-up with carbide inserts on each bit leg for gauge protection. Special features of these bits included harder carbide buttons on the gauge row of the cores and additional clearance in the bearings for more fluid circulation. Two core heads were 8 1/2 inch which cut a 4 1/2" core. Two core heads which were specially constructed for this project (described below) were 7 7/8" diameter which cut a three inch core.

Formations

The SSSDP well was drilled in sedimentary formations. These formations were primarily mudstone, conglomerate, siltstone, sandstone, claystone and shale. The formations contained a high degree of mineralization which changed with depth (and which were an indication of thermal regimes). Two short sections of intrusive were drilled at 9440-50 feet and 9500-30 feet. With increasing depth the formations exhibited increased metamorphism becoming hornfelsic and silicified. The cores contained both open and mineral filled fractures.

The HDR well was drilled from 9285' below a milled out section of 9 5/8" to 13,300 feet in granitic basement rock which had compressive strengths of 18,000 to 40,000 psi.

Directional Nature

The SSSDP well was designed as a straight hole. However, the highly fractured nature of the formations caused severe directional problems below the 13 3/8 inch casing at 3500'. Drilling techniques using light bit weight and various stabilized bottom hole assemblies were employed in the 12 1/4" hole. However, eventually below the 9 5/8" seven downhole turbine runs (from 6079' to 6319') were used to make directional corrections to avoid violating the eastern lease lines. The hole was turned to the south and the hole angle dropped from 8 1/4 to 3 degrees. Because of the hole conditions, high temperature and the low angle and direction of the hole no additional surveys were made during drilling below about 9400 feet.

The HDR well was re-directed below a milled out section of the 9 5/8" casing. The hole angle was continually dropped from 22 degrees to about 10 degrees. Two course corrections were with downhole moineau moters between 11,015' and 11,315'. The hole was relatively low curvature in the cored sections.

Hole Problems

Besides the directional control problems, severe lost circulation was encountered in the SSSDP well below the 9 5/8" casing. Drilling and coring were plagued by these problems with the drill string becoming stuck several times. Also, drilling and coring were conducted without circulation in several intervals. The primary drilling fluid in the SSSDP well was light weight polymer and gel used from surface to 10,475'. The fluid additives and properties varied with the temperature. Considerable lost circulation material was used in the 8 1/2" hole.

The primary hole problem on the HDR well was the drag due to the nature of the friction between the drillstring and formation which was accentuated by the up-hole hole curvature. The drilling fluid was a lightly treated sepiolite system designed primarily to provide lubricity to the drillstring and clean the hole effectively.

CORING OPERATIONS

Complete listings of the conventional cores taken in the two wells are contained in Tables 1 and 2. Two unconventional cores are recorded by the scientists on the SSSDP. These cores were taken while fishing with core "baskets".

The coring in the upper 4600' of the SSSDP well was very successful. The first three cores were cut with a 30' barrel. Cores 4 through 12 were cut with a 60' barrel with a full 60' being cut for five of the cores. Drillpipe connections were made successfully on all these cores. The core catcher jammed on core No. 6 after a connection. On core Nos. 10 and 11 the core jammed on a connection. Core No. 12 jammed in the catcher. After core No. 12 only 30' barrels were used for all successive cores.

Conventional 30' barrels were used on the first two runs in EE3A which cut a 4" core. A special 15' barrel was used on core No. 3 and two tandem 15' barrels were run on core No. 4 which cut a three inch core.

Core Bits

In the SSSDP well four types of core bits (heads) were used. All coring equipment was made by the same company.[3] The RC476 had polycrystalline diamonds (stud mounted) cutters with natural diamonds on the O.D. and I.D. gauge. Two 9 7/8" and one 8 1/2" RC476's were used. These performed well in the soft and medium soft sections of the hole. Penetration rates were often comparable to drill bit rates. Cutter wear and breakage of the polycrystalline diamonds became a problem as the formations became harder and more fractured. A hard, abrasive formation head, the SC226, which had small, densely set, synthetic polycrystalline diamond cutters with natural diamond O.D. and I.D. cutters was used in the harder, fractured formations. The penetration rates were generally very slow with these bits varying from 1/10 to 1/2 the drill bit rates. The C201 was a harder formation version of the SC226 and cut very slowly.

Three types of bits were used on EE3A. The No. 1 corehead was similar to the C201 a bore run on a NaviDrill Mach 2. The penetration rate was very slow and the bit was destroyed in the hard abrasive granite. The No. 2 run was with a specially designed polycrystalline and natural diamond bit produced by DOWDCO. The bit was rotary driven from the surface. This bit also penetrated very slowly and was damaged, in only three feet. Run Nos. 3 and 4 were with a special hybrid core bit with tungsten carbide roller core cutters which used polycrystalline diamonds on studs for internal trimmer cutters.

The hybrid bits cut at about 50% of the drill rate. Both bits cut full barrel intervals. However, some core was lost. The primary problem with these bits was the bearing wear. The slower rotary (and a pilot hole described below) on run No. 4 which cut 30', twice the interval of run No. 3 seemed to reduce the wear.

Barrels and Catchers

Standard steel barrels were used on all the HDR runs and on the first 12 runs on the SSSDP well. Barrel and catcher jamming began limiting the coring intervals in the SSSDP well. Aluminum barrels with slip and dog catchers were used on runs Nos. 13 and 19. These initially performed well and helped reduce the barrel and catcher jamming problems. A steel barrel with a chromed inner surface had been ordered when the barrel jamming problem started occuring. It was used along with a slip and knife catcher on run Nos. 20 through 33. Barrel jamming continued to be the major problem limiting the cored footage.

On the HDR well core Nos. 3 and 4 used a slip and knife catcher and orientation surveys were taken at the end of each core run. The scribe mark on the core was generally very faint but orientation was possible. The helical nature of the scribe mark on both cores indicated core rotation. This was probably due to the high drag on the cores from the trimmers.

Hole Size

Barrel stabilization appeared to be a problem where coreheads were less diameter than the drill hole. This did not seem to be a problem in the softer, straight upper portion of the SSSDP well. Also, reaming the hole after core runs became a major problem in the harder, fractured formations. Severe wear and damage was occuring to the outer bit teeth. This was one of the major reasons for abandoning the 60' core barrel runs. Bit gauge wear became a problem below 9400' and reaming with the core head on run No. 33 caused damage to the head. Thus, on run No. 34 a 7 5/8" corehead and smaller barrel was used. The 7 5/8" size was selected to give a sufficient shoulder for reaming to 8 1/2" to help alleviate pinching of the drill bit.

In well EE3A a 7 7/8" pilot hole was first drilled to run the 7 7/8" hybrid bit in the 8 1/2" hole. This apparently did help reduce the bit wear and increase the penetration rate.

SUMMARY

Thirty four core runs were made in the Salton Sea well where 792' of hole was cored with 722.1' recovered (91% overall). Potential core was 1290' with the lengths of core barrels run. Thus, only 56% of potential core was recovered. At the HDR Project 55 feet were cored and 44.75' recovered. Potential core was 105' or 42.6% of potential core recovered.

Considerable development in coring equipment and operations must be made to technically and economically core extensively in large diameter wellbores in the geothermal environment. The major problems observed from the coring results in these two wells are:

1. Slow penetration rates of core heads,
2. Jamming of the catchers and barrels,
3. Undergauged hole causing outer dia meter corehead wear,
4. Loss of circulation at the corehead,
5. Deviation control, and hole drag,
6. Short core bit life of the hybrid bits and,
7. Lack of barrel and bit stabilization.

DISCLAIMER AND ACKNOWLEDGEMENTS

Reference to a company, product, name or equipment item does not imply approval or recommendation by the author, the University of California (Los Alamos) or the U.S. Department of Energy to the exclusion of others that may be suitable.

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REFERENCES

1. Elders, W.A. "Continental Scientific Drilling in California: The Saga of the Salton Sea Scientific Drilling Project (SSSDP)", GRC Trans.V.9.

2. Carden, R., Nicholson, R., Pettitt,R., Rowley, J., 1983, "Unique Aspects of Drilling and Completion Hot Dry Rock Geothermal Wells", SPE Paper No. 11373 IADC/SPE 1983 Drlg.Conf.

3. Norton Christensen Composite Catalog 1984 - 1985.

TABLE 1

SUMMARY OF CORING OPERATIONS IN THE

HOT DRY ROCK WELL EE-3A

Core No.	Depth Out (Ft.)	Hole Size (In)	Est. Temp. of	Hole Angle (Deg)	Hd. Size (In)	Hd. Type -No.	Wt. (x1000)	Rot. (RPM)	Circ. Rate (GPM)	Core Time (Hrs)	Core Int. (Ft.)	Core Rate (FPH)	Drill Rate (FPH)	Core Rec'y (Ft.)	% Rec'y	Core Hd. Cond'n
1	9457	8.500	381	18.0	8.500	CH	8/10	NAV	300	8.50	7	1.0	16.00	5.00	71	WO
2	16878	8.500	428	14.0	8.500	DAX	20	55	395	5.50	3	0.6	15.00	2.75	92	W
3	11615	8.500	459	8.5	7.875	X3TC7	8/12	45	292	4.00	15	3.75	3.75	13.00	87	T2 B5
4	12469	7.875	504	10.0	7.875	X3TC7	12/14	40	300	5.75	30	5.2	11.90	24.00	80	T2 B5

TABLE 2

SUMMARY OF CORING OPERATIONS IN THE SALTON SEA SCIENTIFIC DRILLING PROJECT

Core No.	Depth[1] Out (Ft.)	Hole Size (In)	Est.[2] Temp. (F)	Hole[3] Angle (Deg)	Hd. Size (In)	Hd.[4] Type -No.	Wt. (x1000)	Rot. (RPM)	Circ. Rate (GPM)	Core Time (Hrs)	Core[5] Int. (Ft)	Core Rate (FPH)	Drill Rate (FPH)	Core Rec'y (Ft)	% Rec'y	Core[6] Hd. Cond'n
1	1577	17.50	270	1.00	9.875	RC476-1	10/15	70/80	171	3.00	24	8.0	31.0	24.0	100.0	G
2	2013	17.50	315	1.00	9.875	RC476-1	15/20	70/80	171	4.00	30	7.5	27.0	30.0	100.0	G
3	2477	17.50	365	1.25	9.875	RC476-1	10	70	171	3.50	30	8.5	28.0	30.0	100.0	G
4	3030	17.50	420	2.50	9.875	RC476-1	10	50	214	3.00	60	20.0	28.0	55.0	95.0	SW
5	3167	17.50	429	3.00	9.875	RC476-1	8/10	70	214	2.50	60	24.0	40.0	54.7	92.0	SW
6	3505	17.50	447	3.75	9.875	RC476-1	8/10	70	214	5.50	35	6.3	19.5	34.0	97.0	WO
7	3850	12.25	465	3.75	9.875	RC476-2	10/15	65	257	5.50	60	10.9	22.4	56.6	94.0	G
8	4067	12.25	477	3.75	9.875	RC476-2	10/20	60	257	5.00	60	12.0	19.3	60.0	100.0	G
9	4301	12.25	489	3.75	9.875	RC476-2	10/20	70	214	3.50	60	17.1	19.3	59.0	98.0	SW
10	4334	12.25	491	3.75	9.875	RC476-2	10/20	60	214	3.50	33	9.4	13.9	33.0	100.0	GWO
11	4643	12.25	508	3.75	9.875	MC201-3	10/15	60	214	3.50	33	9.4	11.9	33.0	100.0	G
12	4682	12.25	510	4.00	9.875	MC201-3	12/15	60	257	2.00	6	3.0	13.9	3.5	59.0	BW
13	5218	12.25	538	4.75	9.875	MC201-3	10/18	55	257	8.50	30	3.5	10.8	30.0	100.0	BW
14	5591	12.25	550	7.25	9.875	MC201-3	10/20	45/60	300	6.50	17	2.6	16.0	17.0	100.0	BW
15	6044	8.50	572	7.25	8.50	SCP-4	20/25	50	385	11.00	18	1.6	7.4	18.0	100.0	G
16	6517	8.50	585	5.50	8.50	RC476-5	10/15	60	385	1.50	11	7.3	27.0	11.0	100.0	G
17	6571	8.50	586	5.50	8.50	RC476-5	10/15	50	385	0.80	13	16.2	36.0	13.0	100.0	D
18	6889	8.50	594	5.00	8.50	RC476-5	10/15	70	340	0.50	9	18.0	21.0	5.0	56.0	G
19	7109	8.50	599	5.00	8.50	RC476-5	6/7	45	340	1.00	9	9.0	19.0	6.0	66.0	D
20	7313	8.50	605	5.00	8.50	SC226-6	10/12	45	340	2.00	13	6.5	11.0	11.0	85.0	G
21	7547	8.50	610	5.00	8.50	SC226-6	10/15	65	340	3.00	30	10.0	10.0	28.0	92.0	G
22	7734	8.50	614	5.00	8.50	SC226-6	15/20	60	340	2.50	30	11.3	21.0	30.0	100.0	G
23	8158	8.50	625	5.00	8.50	SC226-6	10/15	60	340	4.50	25	5.6	11.6	25.0	100.0	G
24	8395	8.50	631	4.25	8.50	SC226-6	10/12	60	350	2.70	7	2.6	26.0	7.0	100.0	G
25	8604	8.50	636	3.75	8.50	SC226-6	10/18	60	252	3.30	19	5.7	26.1	15.0	77.0	G
26	8807	8.50	641	3.75	8.50	SC226-6	15/18	60	252	2.00	7	3.5	21.7	5.5	78.5	G
27	9027	8.50	646	2.75	8.50	SC226-6	18/20	60	342	4.50	23	5.1	15.0	5.0	21.0	G
28	9098	8.50	648	4.00	8.50	SC226-6	12/15	40	342	2.00	3	1.5	15.7	3.0	100.0	D
29	9253	8.50	652	2.75	8.50	SC226-6	12/15	40	342	3.50	5	1.4	11.0	4.0	80.0	D
30	9458	8.50	657	----	8.50	SC226-6	12/18	50	190	4.50	5	1.1	6.0	3.0	60.0	WO
31	9473	8.50	657	----	8.50	SC226-7	8/15	55	190	3.50	15	4.3	8.9	6.5	43.0	WO
32	9476	8.50	657	----	8.50	SC226-8	10/20	60	190	0.80	3	4.0	20.5	2.0	67.0	G
33	9698	8.50	662	----	8.50	C201-9	5/10	50	257	2.00	4	2.0	21.0	3.5	87.5	W
34	9912	8.50	668	----	7.625	C201-10	20	45	300	8.50	5	0.6	8.0	0.8	15.0	W

1. Measured depth from kelly bushing - 28.35'AGL (GL-200'SS).
2. Equilibated geothermal temperature data in process of being obtained.
3. Directional surveys were not taken below 9500' due to hole problems and temperature limitations.
4. "No." refers to the corehead number.
5. Sixty (60) foot long barrels were run on cores No.4 through 12. All other barrels were 30' length. A 5 1/2" O.D. core was taken with 9.875" heads, a 4" core was taken with 8.5" heads and a 3 1/2" core was taken with the 7 5/8" head.
6. G - Good condition; SW - Slightly worn; WO - Worn out; BW - Badly worn; GWO - Gauge worn out; D - Dull

Note: The core recovery footage was taken from the core company reports. Actual geologists' footage will be different.