Geothermal Resources Council, TRANSACTIONS, Vol. 10, September 1986

THE SALTON SEA SCIENTIFIC DRILLING PROJECT: DRILLING PROGRAM SUMMARY

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ABSTRACT

Drilling, coring, logging, and flow testing of well "State 2-14" was completed in March 1986. In the 160 days following spud-in, all the major operational objectives of the Salton Sea Scientific Drilling Project (SSSDP) were met or exceeded. A review of the project costs is presented with an emphasis on unusual or unexpected problems encountered on this scientific/exploratory well. A discussion of the flow test procedures and basic results of commercial interest are also discussed.

INTRODUCTION

Spud-in of the Salton Sea Scientific Drilling Project well took place on October 23, 1986. In the following 160 days, the well was drilled to 10,564 ft, exceeding the target depth objective of 10,000 ft. Thirty-six spot cores were taken, with a total of approximately 725 ft recovered. Two flow tests were conducted, providing fluid samples for scientific study and estimates of productivity from an upper zone at 6,120 ft and a lower interval with mixed flow, primarily from zones at 8,600 ft and 10,475 ft. Downhole logging suites and fluid sampling were performed by researchers (about 425 hrs) and service companies (about 60 hrs), providing additional data to be used in the study of the Salton Sea geothermal resource and the factors that have influenced the geological evolution of the basin.

This paper presents an overview of the management approach, and some of the technical and cost results unique to the project. A brief summary of the flow tests and results is also included. Preliminary reports on the science portion of the program and core drilling are the subject of separate papers being presented at the Conference.

MANAGEMENT SUMMARY

Bechtel, under a contract with the U.S. Department of Energy,* had overall responsibility for design, procurement, and supervision of operations at the site, near Niland, California. The site was made available to the project by Kennecott, holder of an exploration permit from the State Lands Commission. More than 65 competitively bid subcontracts and purchase orders were activated to provide the support services, equipment, materials, and personnel necessary to carry out the complete program.

Consequently, a critical element in project control was the development and use of an accrual system for daily accounting of costs. Suppliers were required to submit work and delivery tickets at the site, as services were performed, that showed estimated actual costs. These, along with estimates for labor, equipment rental, and all other costs, were processed daily to produce a current expenditure report. Individual estimates were cross-checked with bid prices and actual billings at frequent intervals and adjustments made accordingly. The availability of "real time" cost information at the drill site was invaluable in planning and prioritizing engineering and science objectives.

The overall project costs are summarized in Table 1. Prespud activities included a major

Table 1. Summary of Salton Sea Scientific Drilling Program Costs (Does not include the science experiments budget.)

Activity	Period of Performance	Estimated Cost ($1000s)
Prespud	Sept 1984 through Oct 1985	1,720
Drilling and completion	Oct 1985 through Mar 1986	2,975
Coring and Logging	Oct 1985 through Mar 1986	930
Flow Test Facility and Two Flow Tests	Dec 1985 and Mar 1986	680
Standby and Restoration	Apr 1986 through Nov 1986	400
Total Budget		$6,705

*Contract Number DE-AC03-84SF12194

rescoping of the project to eliminate installation of an injection well and high-pressure separator from the flow test facility. Other prespud activities included well design, site layout and preparation, and the negotiation and award of the majority of the subcontracts. The drilling and completion costs were higher than might be expected due to three major problem areas, summarized in Table 2 and discussed in more detail below. Nearly $1 million was spent on directional drilling and lost circulation and well control problems. The estimated net cost of coring was $550,000, for an average cost per ft recovered of about $755. The combined estimated cost of scientific and commercial logging was $380,000.

Table 2. Problem Areas and Estimated Costs Incurred During Drilling and Completion

Activity	Approximate Cumulative Duration	Estimated Cost ($1000s)
Lost Circulation and Well Control	20 days	640
Directional Drilling	18 days	390
Fishing and Stuck Pipe	8 days	275

The project schedule, spanning 26 months, is summarized in Figure 1. The current phase of the project is scheduled for completion in November 1986.

PROBLEM ANALYSIS

The drilling of State 2-14 resulted in some unexpected problems and costs, largely to meet the overriding science objectives. A commercial well typically would be drilled with few, if any, cores taken and would be completed at the highest zone(s) believed capable of commercial production. Few wells in the Salton Sea Geothermal Field have been drilled deeper than 8,000 ft. State 2-14, on the other hand, was to be drilled to at least 10,000 ft, if technically and economically feasible, and to be spot cored at intervals of about every 200 ft, or more frequently if interest dictated. The result was that:

- Fifteen of the 61 drill bits used had up to half of their potential drilling life remaining, when they were tripped out of the hole so a core could be taken. These bits were discarded rather than rerun, to avoid the risk of bit failure and a fishing job or premature tripping for bit replacement before the next coring point was reached.
- All cores taken above 6,000 ft required a followup reaming run to open the borehole to gauge. Loss of roller cone bit gauge and bearing failure was accelerated considerably, especially in the deeper, harder formations.
- Every fluid loss zone encountered as the well was deepened, contributed to a continuing problem. Lost circulation control methods, including setting

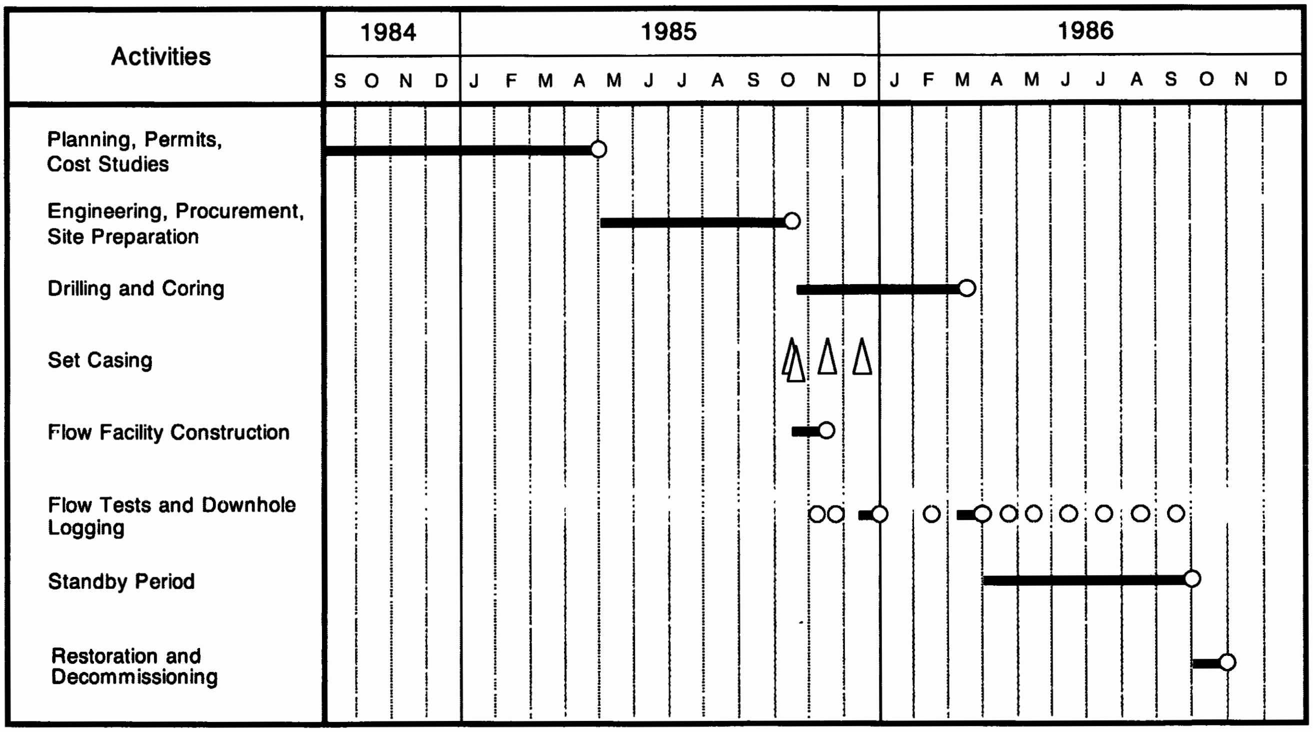

Figure 1. Salton Sea Scientific Drilling Project Schedule

cement plugs, proved to be only temporarily effective. Very high costs were incurred for control materials and lost time to reestablish circulation.

Directional drilling, not included in the original project plan or budget, was required when the path of the borehole deviated several times, approaching the easterly property boundary. Although the final multishot survey failed because of high bottomhole temperatures, the best available information is that the borehole remained on the Kennecott lease.

Drill Bit Usage

A summary of bit usage and cost is presented in Table 3. Average hourly penetration rates when drilling are summarized in Table 4. The average penetration rate was relatively constant at an approximate 25 ft/hr from 3,000 to 8,000 ft, including approximately 550 ft directionally drilled at an average penetration rate of 15 ft/hr. From approximately 9,500 ft, where intrusive igneous dikes were encountered, to total depth (T.D.), drilling became progressively slower. The formation showed complete metamorphosis of the siltstones, mudstones, and sandstones encountered higher in the well, to harder hornsfelsic and quartsitic forms.

Table 3. Bit Usage and Cost Summary

Overall Size	Type	Quantity	Depth Used (feet)
17-1/2	Mill Tooth	6	Surface to 3,500
12-1/4	Mill Tooth	7	3,500 to 6,000
	Carbide Insert	6	
8-1/2	Mill tooth	6	6,000 to 10,475
	Carbide Insert	34	
	Stratapak	1	
6-1/8	Carbide Insert	1	10,475 to 10,564

Total estimated bit cost = $215,000

Table 4. Drill Rate versus Depth

Depth (ft)	Drill Rate (ft/hr) Range	Drill Rate (ft/hr) Approximate Average
0 to 1,000	60 to 1,000	100
1,000 to 2,000	15 to 300	75
2,000 to 3,000	15 to 125	50
3,000 to 8,000	5 to 100	25
8,000 to 9,000	5 to 75	20
9,000 to 10,000	5 to 75	15
10,000 to 10,564	5 to 18	10

Seventeen bits were used during directional drilling (turbodrilling) operations. Bit life averaged about 6 hours. Total footage averaged only about 30 ft per bit, rather than the 150 to 240 ft expected in normal service.

Lost Circulation and Flow Control

Lost circulation zones in the Salton Sea Geothermal Field, as observed in State 2-14, typically result from seismic fracturing that has created a network of vertical and horizontal channels for fluid transport. Between 6,000 ft and T.D., nine major fluid loss zones were encountered, as summarized in Table 5. As each zone was penetrated, conventional lost circulation materials (LCM) and control techniques were tried to regain circulation. Zones which were not kept in check by this method were eventually covered with a cement plug. As an intermediate solution, LCM/cement pills consisting of a 50 bbl LCM pill mixed with 50 or 100 sacks of Portland cement were tried. Pills were placed across each loss zone, allowed to set up, and then squeezed to 200 to 300 psi. While this procedure was often successful, the plugs usually broke down within a week. As the well was deepened and more and more zones were exposed, the time required to mix and place LCM pills and the cost of the materials became excessive. As shown in Table 6, the situation became critical between 9,000 and 10,000 ft when the average ft/day drilled dropped below 50 ft and the average cost/ft rose above $500. Core bit damage from inadequate circulation and differential sticking were additional concerns.

Table 5. Major Fluid Loss Zones in State 2-14

Approximate Depth (ft)	Maximum Loss Rate (bbl/hr)	Treatment*	Flowed During Second Flow Test
6,120**	66	CEM	Yes?
6,360	45	LCM, CEM	No
6,635	Total	LCM, CEM	Yes?
6,340	35	LCM, CEM	No
8,095 through 8,160	Total	LCM, CEM	No
8,560 through 8,620	Total	LCM, CEM	Yes
8,950	Total	LCM, CEM	No
9,220	80	LCM, CEM	No
10,475	Total	SAND, CEM, Drillout	Yes

* LCM = Lost circulation material with Portland cement
CEM = Full cement plug
SAND = Sand plug

** First flow test flow zone; cemented after first flow test.

Table 6. Drilling and Coring Performance Trends*

Depth Interval	Days to Complete	Average Cost/Day	Average Ft/Day	Average Cost/Ft	Delays
Surface to 3,500	21	$15,500	165	$ 95	One day setting conductor; one day fishing
3,500 to 6,000	23	$17,000	110	$155	Two days fishing; two days injectivity testing
6,000 to 7,000	20	$19,500	50	$390	Six days directional drilling; two days fishing
7,000 to 8,000	10	$19,500	100	$195	Two days directional drilling; two days lost circulation control
8,000 to 9,000	11	$26,000	90	$290	Five days lost circulation control
9,000 to 10,000	27	$24,500	35	$660	Damaged core bits; seven days lost circulation control and cementing; two days stuck pipe; two days well control
10,000 to 10,460	5	$23,000	90	$250	Two days well control; one day stuck pipe

* Excludes casing, flow tests, and logging activities.

At a depth of 9,450 ft, the decision was made to set full cement plugs across all the open zones. Several of these plugs broke down during subsequent drilling to T.D. and lost circulation and well control problems continued to plague the drilling operation. By the time the well was T.D.'d, daily mud and chemical costs were averaging over $5,000. A partial summary of mud and chemical usage and overall costs are shown in Table 7.

WELL COMPLETION AND FLOW TESTING

First Flow Test Configuration

After drilling out of the 9-5/8 inch casing set at 6,000 ft, a 66 bbl/hr fluid loss zone was encountered at 6,120 ft. After drilling a 100 ft rat hole, the borehole fluid was replaced with water and the wellhead was installed and tied into the flow test facility. Wellhead pressure built to 160 psi after being shut in for about 24 hours. However, nitrogen stimulation was finally required to induce flow.

A James' tube was used to estimate the potential productivity of the zone. The extremely high total dissolved solids (250,000 to 300,000 ppm), presented both a physical challenge, in contending with deposition rates that sealed over the lip pressure port in 10 to 20 minutes, and an analytical challenge, in mathematically compensating for salinity effects.

Table 7. Most Frequently Used Mud and Chemicals* and Total Estimated Cost

Product Type	Purpose	Approximate Total Used
Bentonite clay	Viscosifier	1,945 sacks
Sepiolite	Viscosifier	9,130 sacks
Barite	Weight control	3,885 sacks
NaOH	pH control	370 sacks
Cotton seed hulls/ pellets	LCM**	1,220 sacks
Wood chips/ nut hulls	LCM	1,050 sacks
Vegetable/ other fiber	LCM	900 sacks
Polymer	LCM	800 gallons
Granular battery casings	LCM	85 sacks
Diesel fuel	Free stuck pipe	400 barrels

Total estimated mud and chemical cost = $460,000

* A total of forty different products were used.
** Lost circulation material.

Second Flow Test Configuration

No major fluid loss zones were encountered between about 9,200 and 10,450 ft. The loss of circulation at 10,475 ft led to speculation that a new, possibly lower salinity reservoir might have been discovered. The well completion design was modified, within the limitations of available funding, to increase the chances of flowing the well solely from this lowest zone. The approach taken was as follows:

1. Temporarily plug the bottom flow zone. Several 50 bbl LCM pills (without cement), 86 sacks of #20 silica sand, and approximately 400 cu ft of cement disappeared into this fracture system before a cement plug held.

2. Hang down a 7-inch liner from 5,700 to 10,136 ft to cover over all of the upper zones. It was hoped that any upper zones that started to flow during testing would bridge off, preventing flow down around the liner into the borehole. Installing the liner was a delicate operation because the well was alternately taking fluid or flowing, over a period of a few hours. The well would begin flowing by the time the drill string was tripped out after a cooling run.

3. Drill out the cement plug and make a 100 ft rat hole. The cement plug was less than two feet thick!

The flow test facility was basically identical to that used on the first test. Wellhead pressure rose to 250 psi during the 24 hour shut-in period and the well flowed spontaneously.

Flow Test Results

The results are summarized in Table 8. The well flowed from a single zone on the first test, and drilling fluid contamination was flushed out after about 6 hours of flow, producing good quality fluid and gas samples for science analysis. The well was flowed for about 48 hours.

The second flow test was too brief to allow uncontaminated fluid production. It was concluded when the storage pit was full after 36 hours of flow. Continuous temperature measurements made after brine reinjection indicated that flow occurred behind the liner from the zones identified in Table 5. The percent contribution of each of the zones is unknown, but a major portion of the reinjected brine appears to have entered the zone at 8,560 to 8,620 ft. This zone would appear to have significant commercial potential.

CONCLUSIONS

The heart of the Salton Sea Geothermal Field appears to contain previously undiscovered, deep hydrothermal zones that may be of commercial, as well as scientific interest. An extended flow test of the isolated deeper flow zones in State 2-14 will be required to provide clean fluid samples for scientific study and to more fully assess their commercial potential. Deepening the well might also lead to further discoveries of mutual value to science and industry. The SSSDP has demonstrated that difficult technical problems can be managed, to meet the objectives of scientific investigators. The key is working together to achieve a mutual understanding and balancing of the scientific objectives and the technical limitations.

Table 8. Preliminary Flow Test Results*

	Well Depth (ft)	Estimated Flow Zone(s) (ft)	Approximate Duration (hr)	Flow Rate (lb/hr)	Wellhead Temperature (°F)	Wellhead Pressure (psig)	Estimated Enthalpy** (Btu/lb)
First Test	6,227	6,120	4	600,000	400	200	400
			12	80,000	460	440	400
			2	430,000	410	220	400
			9	150,000	460	450	400
Second Test	10,564	[6,100	3	475,000	445	310	520
		6,600	24	280,000	475	450	~480
		8,800	1	700,000	460	380	480
		10,475]	4	300,000	490	485	450

* Analysis by GeothermEx, Inc.

** Based on James' correlation with TDS correction.