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UPDATE ON SLIMHOLE DRILLING

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ABSTRACT

Sandia National Laboratories manages the US Department of Energy program for slimhole drilling. The principal objective of this program is to expand proven geothermal reserves through increased exploration made possible by lower-cost slimhole drilling. For this to be a valid exploration method, however, it is necessary to demonstrate that slimholes yield enough data to evaluate a geothermal reservoir, and that is the focus of Sandia's current research.

BACKGROUND

Although the vast majority of drilling technology used in the geothermal industry is derived from the oil and gas industry, geothermal requirements are qualitatively different. There are hard, abrasive, and fractured rocks; high temperatures; and underpressured formations, frequently containing corrosive fluids. All these factors create a more rigorous environment than normally found in oil and gas drilling. The service and drilling tool industries have little incentive to address these problems, since the number of geothermal wells drilled in a year is about 0.1% of the corresponding number for oil and gas. This lack of commercial R&D is the primary rationale for DOE's support of technology development.

Drilling costs associated with exploration and reservoir assessment are a major factor affecting future geothermal development. Slimhole drilling has been shown to reduce oil and gas exploration costs by 25 to 75%, but the more hostile conditions for geothermal resources present technology challenges which must be solved before the cost impact there can be thoroughly evaluated.[1] Once demonstrated, slimhole drilling technology will have application to geothermal exploration and reservoir assessment in both the U. S. and international markets.

RECENT ACTIVITIES

Sandia examined the basic feasibility of slimhole exploration with in-house analysis, field experiments on existing geothermal coreholes, and collection of an extensive data set from comparable drilling in Japan. We then negotiated an agreement with Far West Capital, which operates the Steamboat Hills geothermal field, to drill and test an exploratory slimhole on their lease. The principal objectives for the slimhole were development of slimhole testing methods, comparison of slimhole data with that from adjacent production-size wells, and definition of possible higher-temperature production zones lying deeper than the existing wells. This work has been reported in detail[2].

Sandia has contracted with S-Cubed to conduct extensive collection and analysis of data from Japanese slimholes and production wells in common reservoirs. Results from two geothermal fields support a correlation in productivity between different-sized holes[3]; this work is being extended to another, higher-temperature field in Japan.

Two industry cost-shared exploratory slimholes were drilled during 1995. The first was in the Vale Known Geothermal Resource Area (KGRA) in eastern Oregon; the second was on the north-west flank of Newberry Caldera, approximately 20 miles south of Bend, Oregon.

NEWBERRY EXPLORATORY SLIMHOLE

As part of an attempt to evaluate the commercial potential of a location within the Newberry

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DISCLAIMER

KGRA, CE Exploration (CEE), a subsidiary of California Energy Company, Inc., drilled two slimholes in the projected reservoir area. One hole was drilled entirely by CEE, the other was cost-shared with Sandia. Both holes were drilled with a Longyear minerals-type core rig. The cost-shared hole reached a depth well below 4500' in a drilling operation which lasted just over 100 days, including continuous coring to TD, directional drilling, and testing. Precise depths, temperatures, and gradients for this hole are proprietary at this time, but both slimholes predicted temperature gradients at depth which were later realized in nearby production-size wells.

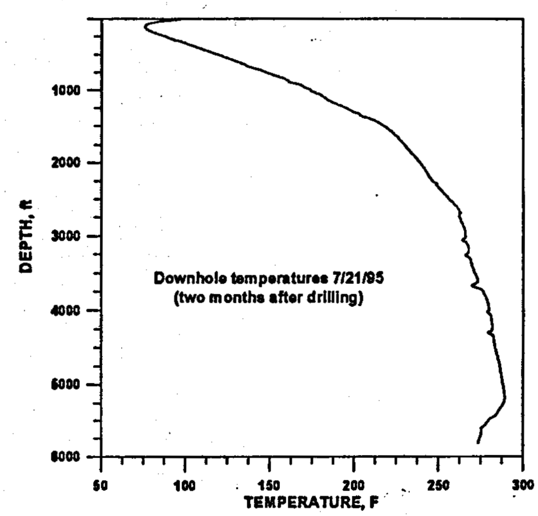

Figure 1 - Temperature in Vale Exploratory Slimhole

VALE EXPLORATORY SLIMHOLE

In cooperation with Trans-Pacific Geothermal Corporation, another slimhole was drilled in the Vale KGRA in eastern Oregon. In addition to possible discovery of a new geothermal resource, this situation offered an opportunity for direct cost comparison between the slimhole and a conventionally-drilled exploration well approximately two miles away. TGC drilled this previous well in early 1994, and it was completed to roughly the same depth as that planned for the slimhole.

The principal objectives for this project were the following: development of slimhole drilling and testing methods; cost comparison with a recent, nearby; conventionally-drilled exploratory well; comparison of reservoir and performance data from this well with that from subsequent production-size wells; and evaluation of commercial geothermal potential at this location. Since both formation temperatures (see Figure 1) and permeability (less than 1 Da-ft) were lower than expected, it is unlikely that commercial development will take place in this location. The drilling and testing, however, were successful in showing that slimholes are informative and cost effective.

To meet our testing and data collection goals for this well, it was designed to meet the following criteria:

- Drill to TD at minimum cost consistent with necessary testing.
- Obtain a competent cement job on all casing, to allow extended production testing.
- Maintain HQ (3.85") hole diameter as deep as possible, to allow setting packers for isolation of possible production/injection zones.

The well design (Figure 2) has 7" casing to 510' and 4-1/2" casing to 3111 feet. The drilling program used a Tonto UDR-5000 core rig with conventional rotary tools to drill the top 3112 feet of hole; minerals-type coring tools were then used to core the interval of interest from casing shoe to TD. This approach combined the cost savings of a slimhole drill rig, doing fast rotary drilling in the upper part of the hole, with the scientific and reservoir data obtained from core in the potential production zone.

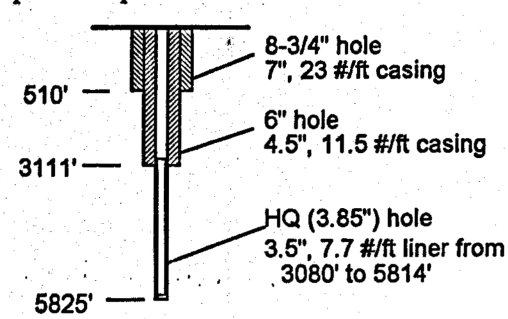

Figure 2 - TGC 61-10 Design

Drilling was relatively continuous, with all testing (other than temperature logs) reserved until hole completion at 5825 feet. The following tests were performed at TD: injection tests into the complete open-hole section, with pressure shut-in data; bailing from the bottom 500' of the hole, which was isolated with an inflatable packer, and then measuring temperature change in that section; repeated temperature logs in the hole, following well completion with a 3-1/2" liner from 3080' to 5814'.

Numerous temperature logs were taken with Sandia's platinum-resistance-thermometer (PRT) tool which, along with a Sandia logging truck, remained on-site for the entire project. This instrument uses a simple resistance bridge, with changes in resistance measured from the surface through a four-conductor cable. Since there are no downhole electronics, temperature drift with time is negligible and the PRT temperature measurements were considered the reference standard for these tests. Static temperature logs (no flow in hole) were done with this tool when coring operations were suspended for bit trips, rig maintenance, or other time intervals that would permit the hole to equilibrate with the static temperature gradient.

After the hole reached TD, a pressure-temperature storage, or "memory", tool was also used to compare temperature data with that previously taken by the PRT tool and to collect downhole pressure data during the injection and shut-in tests. This tool, part of Sandia's on-going program in Instrumentation Development[4], has a Dewar flask around an electronic memory which stores data (approximately 3,000 data points total capacity) that can later be downloaded into a laptop computer. This tool's primary advantage is its ease of operation, since it can be run into the hole on the rig's wireline and specialized logging trucks are not required. As an experiment, the tool was also run into the hole inside a core-barrel "cage" while tripping the drillstring and gave good results.

A major objective of the slimhole program is to demonstrate not only that the smaller wells give sufficient data to evaluate a reservoir, but that they do it more cheaply than conventionally-drilled large holes. The Vale slimhole presented an ideal situation for cost comparison because a rotary-drilled exploration hole had been completed less than two miles away, to approximately the same depth, in February 1994. The table at the end of this paper gives a breakdown of costs for both wells, and helps to define where major cost differences occur.

DISCUSSION

There are several points to note in the cost comparison:

- Even though charges by the drilling contractor were greater for the slimhole than for the A-Alt hole, lower ancillary costs for the slimhole made the total project much cheaper. Part of the greater rig cost was caused by the longer time required for the slimhole, and the remainder is due to the rig day-rates. It is not obvious that the core rig for the slimhole ($4990/day plus $5-$9/foot) should be more expensive than the rotary rig for A-Alt ($5640/day), but day-rates for drill rigs obey the same principles of supply and demand as other commodities. At the time A-Alt was drilled, rotary rigs were available in abundance and consequently were bid at relatively low prices, while core rigs, mostly employed by the minerals industry, were in short supply when bids for the TGC 61-10 slimhole were solicited.
- The only aspect of the earlier well which made it inherently more expensive was the directionally drilled interval. Beside the explicit costs of directional tools and services, there may have been additional rig days and bit costs, but even after deducting these items, there are clear savings for the smaller hole.
- The drilling-fluids expense for the slimhole was slightly greater than for A-Alt, but it was inflated by the complete loss of circulation in the lower part of the hole. This meant that we were continually pumping 10 to 15

gpm of mud down the hole for the last 20 days of drilling. A slimhole which did not lose total returns would have a much smaller mud cost.

- Even though more than half the total footage was rotary-drilled, the smaller bits used in the rotary section and the less expensive core bits in the cored section greatly reduced the cost of bits and tools. In the cored section, the simplified BHA also eliminated the cost of stabilizers and drill collars.
- Smaller sizes of the rig, pad, and sump reduced rig mobilization and site construction costs.
- A mud logging service company was only used for the rotary section of the hole, although we did continue to rent their H_2S monitors for the duration of the project. Once core was being retrieved, cuttings analysis was no longer required. Similarly, contract drilling supervision was only used during rotary drilling. While outside consultation was useful for design of bit hydraulics and BHA programs, these activities are considerably simplified in core drilling and the drillers are accustomed to making these choices independently.
- Smaller casing sizes, with correspondingly smaller cement volumes, were less expensive for the slimhole. Normally, there would be even more of a cost advantage to the smaller hole, but the 6" hole was washed-out over several intervals, requiring more cement for the 4-1/2" casing than originally estimated. Washed-out intervals may have been caused by excessive bit hydraulics, designed in an effort to increase drilling performance. If this was the case, then the trade-off with a $66,000 cement job was not cost-effective.

CONCLUSIONS

Although the Vale slimhole was geologically informative and the drilling went well, it was, unfortunately, drilled in a location which holds little promise for commercial geothermal development. Still, several useful conclusions can be drawn from this project.

- Drilling this hole to the same depth as a nearby rotary hole provided information of the same quality at substantially lower cost.
- With some refinement of techniques (hydraulics, etc.) used in the rotary part of the hole, cost savings could have been even greater.
- Total well cost is sensitive to the ratio of rotary-drilled interval to core-drilled interval. For example, see the table below. If rotary drilling had only gone to 2000', then the extra

Type of drilling	Hole advance ft/day	Avg cost, $/day	Avg cost per foot
Rotary	289	14,408	$50
Coring	129	10,573	$82

1100' feet of coring would have increased the total cost by approximately $32/foot for that interval. (These costs-per-foot are much lower than shown in Table 1 because they include only cost during drilling; i.e., no casing, cement, site preparation or other non-drilling costs.)

- Given the availability of a storage-type logging tool, the method of taking a temperature log with the tool in a core barrel while tripping pipe has several advantages. It takes almost no extra rig time, it happens when the hole has not seen circulation for a period of several hours, and it is extremely safe (for the logging tool) compared to running the tool in an open hole, which might be fractured, caving, or sloughing.
- If a hole has several intervals which appear (from core examination) to have high permeability, then an inflatable packer is useful in evaluating these intervals individually. If significant lost circulation has been treated by pumping LCM, which may have plugged some of the fractures, then swabbing the hole can relieve this situation and give a better indication of that interval's true permeability. To do this, a specifically designed swabbing tool would have been more effective than the make-shift one used on this hole.

Drilling is cheaper for slimholes than for production wells because the rigs, crews, locations, and drilling fluid requirements are all smaller; because site preparation and road construction in remote areas is significantly reduced, up to and including the use of helicopter-portable rigs; and because the very fine cuttings and removing a substantial part of the hole volume in the form of core mean that it isn't necessary to repair lost-circulation zones before drilling ahead.

If the resource evaluation program calls for production or injection tests from an exploratory well, these are also easier with a slimhole because they involve handling much less fluid than a larger well. Finally, the same attributes that reduce the cost also greatly reduce the environmental impact. As exploration expands into new areas such as the Pacific Northwest, this may become the critical criterion in regulatory agencies' decisions on whether to issue permits. This technology appears to be the best hope of increasing exploration in an attempt to enlarge the nation's proven geothermal reserves.

RECOMMENDED FUTURE WORK

Since all our slimhole operations to date have supported the validity of slimhole drilling as a lower-cost exploration technique, we should seek other opportunities for cost-shared projects in geothermal reservoirs where subsequent production wells will give comparisons between slimhole tests and production data. This would be part of a general effort to do exploratory drilling and testing in reservoirs with different flow characteristics, and to compare those results with production wells in the new reservoirs.

A consequence of moving to other types of reservoirs will be the increasing need for flow modeling capability, especially in terms of coupling a reservoir simulator to a wellbore simulator. Although little modeling was done for this well testing, it will be important to simulate the flow from the reservoir into and up the wellbore when working in a reservoir where production tests can be done.

The pressure-temperature log taken while tripping drill pipe with the memory tool in a core barrel was successful, having as a principal defect the necessity for hand entry of drill pipe length during the trip. A simple drill-pipe-length encoder should be developed to expand the opportunities for this type of logging on core rigs. An encoder would produce time-depth data which could be merged with the logging tool's time-pressure/temperature data to generate a curve of depth versus pressure and temperature.

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Well Name:	**A-Alt**	**TGC 61-10**
Depth	5757'	5825'
Completion	14" line pipe to 62' 9-5/8" casing to 506' 7" casing to 3010' 5" slotted liner, 2902'-5723'	10" line pipe to 29' 7" casing to 510' 4-1/2" casing to 3111' 3-1/2" H-rod, 3080'-5814'
Rig days	31 + 5 standby	40

WELL	A-Alt	TGC 61-10
Rig Charges (day rate, footage, crew per-diem)	184,955	254,837
Rig mobilization and de-mob	87,860	43,560
Site construction and maintenance	57,700	29,998
Mud logging	26,040	13,490
Bits and downhole tools	67,279	27,978
Directional	37,374	0
Fishing	3,200	1,695
Rentals	28,090	20,182
Fuel and water	10,350	5,570
Drilling fluids	48,421	48,468
Casing, casing crews, and cement	172,817	107,076
Logging	58,376	14,929
Trucking and additional labor	36,723	12,895
Equipment maintenance	11,530	1,260
Drilling engineering	56,940	13,790
Wellhead and miscellaneous	32,670	42,555
TOTAL	920,325	638,334
Cost per foot (*excluding* directional costs)	$153	$110