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COST EFFECTIVE USE OF SLIM-HOLE DRILLING AND LOGGING TO EVALUATE AND DEVELOP GEOTHERMAL PROPERTIES

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ABSTRACT

The use of a series of successively deeper slim-hole drilling and logging programs is a cost effective way of proving up a geothermal property, prior to siting a commercial well.

INTRODUCTION

Geothermal resources are found in a variety of geological environments. Because of this, much of the geothermal exploration and development strategy is site dependent. An exploration strategy applicable to recent volcanic areas, such as the Cascades, are not necessarily applicable to the Basin and Range Province or the Imperial Valley. One technique, which is universally helpful, is subsurface temperature. This is essentially a direct detection technique. If commercial temperatures are not found at economic drilling depths, there is no viable geothermal property. Subsurface temperature anomalies, caused by geothermal resources can, and do, vary with depth Hill (1985). The use of successively deeper slim-hole temperature holes provides a cost effective method of maturing a geothermal property prior to siting a commercial geothermal production well (Hill, 1985; Combs and Dunn, 1992). The addition of geophysical logs to selected deep temperature holes greatly enhances their value.

THREE-PHASE GEOTHERMAL EXPLORATION DRILLING PROGRAM

A geothermal prospect begins as an explorationist dream, hopefully based on regional geology, tectonics, and/or geophysics. Until it has been proven up and thoroughly evaluated, it remains just a dream.

Once a target area has been identified, it can be evaluated by drilling a large number of shallow temperature holes, using small 'shot-hole' type drill rigs. While called shallow temperature holes, 'shot-hole' type drill rigs can and have efficiently drilled temperature holes as deep as 1000 ft. Cuttings from such a program can be used for correlation and lithology control. At TD, these shallow holes are cased with black pipe and filled with water. After thermal stabilization, temperature logs can be obtained using a hand operated winch. An isothermal map, Figure 1, the product of such a program.

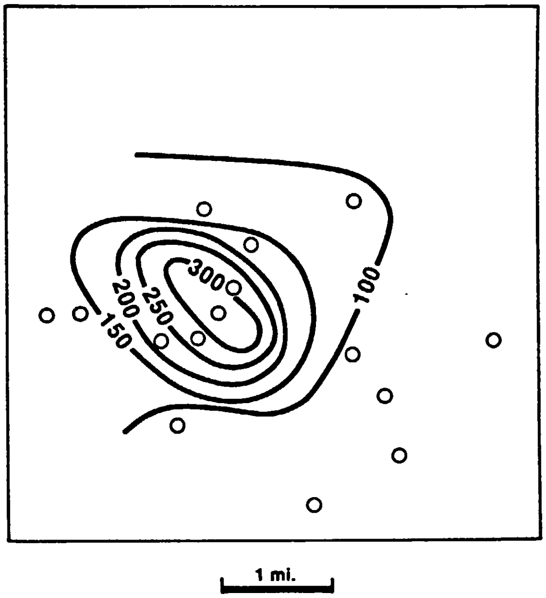

FIGURE 1: Typical shallow temperature hole isothermal map at 500 ft.

Temperature information obtained from the shallow drilling program can be used to develop a series of isothermal maps, temperature cross-sections, and iso-gradient maps. A shallow temperature hole drilling program is an efficient way to quickly evaluate a group of geothermal prospects. Those not worthy of further consideration are quickly eliminated. Those which yield encouraging shallow temperature and/or gradient data can be further evaluated.

Subsurface temperature anomalies often change with depth. Shallow temperature or gradient anomalies can be evaluated by drilling selected intermediate depth temperature holes. This drilling program uses larger truck mounted drill rigs (eg: double 20 ft stands), which have been used to drill successfully to depths of up to 4000 ft. These intermediate depth temperature holes are sited to evaluate specific geologic or thermal models developed from the earlier work. Drill cuttings logs are developed, often by a drill-site geologist. Slim-hole and even major vendor geophysical logs can be run in these intermediate depth temperature holes. Their cost is significantly more than the shallow boreholes, so fewer are drilled (eg: 1:10 ratio). Cuttings and full suite geophysical logs from these intermediate depth temperature holes are used to improve the prospect model and calibrate surface geophysical data (Hill, 1985). The primary purpose of these boreholes, however is to obtain temperature information. At TD, they are cased with black pipe and filled with water. After thermal stabilization, temperature logs can be run, using slick-line or slim-hole equipment.

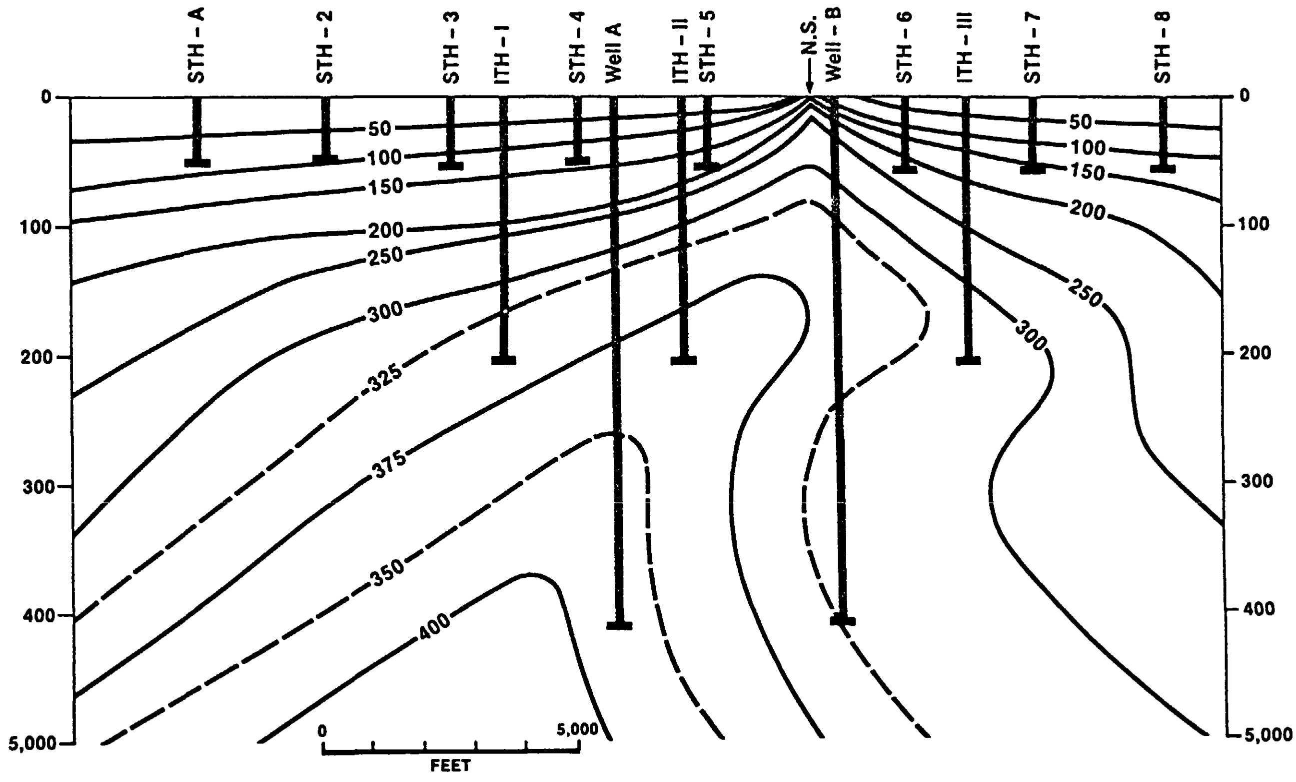

FIGURE 2: Typical temperature section documenting thermal plume.

Once a shallow geothermal anomaly is confirmed with a few intermediate depth temperature holes at selected sites, the prospect has matured to siting a deep test or producible well. Large (double or triple) drill rigs are used for these wells. Complete suites of geophysical logs are run at each casing point. Selective cores are cut and flow tests conducted. The object is to locate high temperature fluids at sufficient quantity that can be produced to generate electricity. Geophysical logs obtained in these wells are used for formation evaluation and to provide physical property information for interpretation of surface geophysical data. The temperature cross-section of Figure 2 is built from 8 shallow and 3 intermediate temperature holes, as well as 2 producible wells. Well B was drilled, on the basis of the shallow temperature hole program, and missed the heart of the thermal plume. Well A was drilled after the three intermediate depth temperature holes had defined the thermal plume and was much more successful.

WIRELINE QUALITY CONTROL

Quantitative usage of geophysical well logs, require high quality data. Most wireline contractors provide several equipment calibration checks. The client can also request additional quality checks, of their own.

One example of client inspired quality control (QC) is to verify the wireline vendor's fluid resistivity bridge calibration, using NaCl solutions of known salinity (and, consequently, known resistivity). Contractor fluid resistivity measurements are used to estimate formation water salinities, often a critical factor in geothermal reservoir evaluation.

Figure 3 illustrates a vendor's fluid resistivity bridge which was obviously not properly calibrated. The calibration check, however, served as a field calibration for that well. Because of the results of Figure 3, the vendor was requested to recalibrate all of their fluid resistivity bridges. Figure 4 is a calibration check of the same vendor's fluid resistivity bridge conducted one month later. The bridge is now properly calibrated.

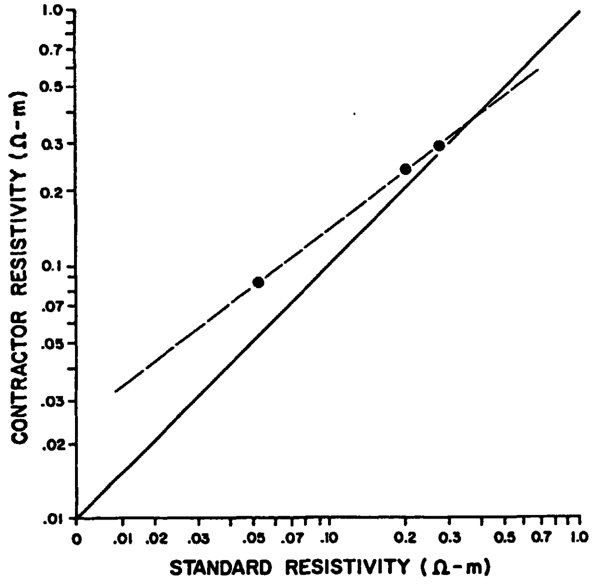

FIGURE 3: Fluid resistivity bridge calibration check indicating improper calibration.

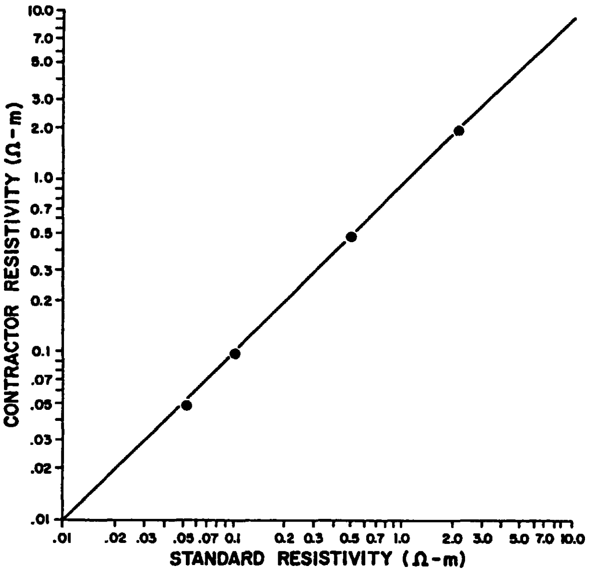

FIGURE 4: Fluid resistivity bridge calibration check indicating good calibration.

Accurate temperature and temperature gradient profiles are critical to the evaluation of a geothermal property. Figure 5 shows two 'stabilized' temperature profiles (by different vendors) in the same borehole. The 10 - 30° F discrepancies between the two results could easily make a difference in the fate of this prospect.

The calibration problems, illustrated by Figure 5, inspired the use of field temperature tool calibration checks, using surface and bottom hole temperatures. Figure 6 illustrates a temperature tool calibration which becomes non-linear above the (surface) water boiling point. These results were forwarded to the vendor who used them to justify development of high temperature oil-bath calibration facilities for his temperature tools. Figure 7 is a temperature tool calibration check conducted after the vendor had installed the high temperature calibration facilities. The non-linear calibration problems of Figure 6 are corrected.

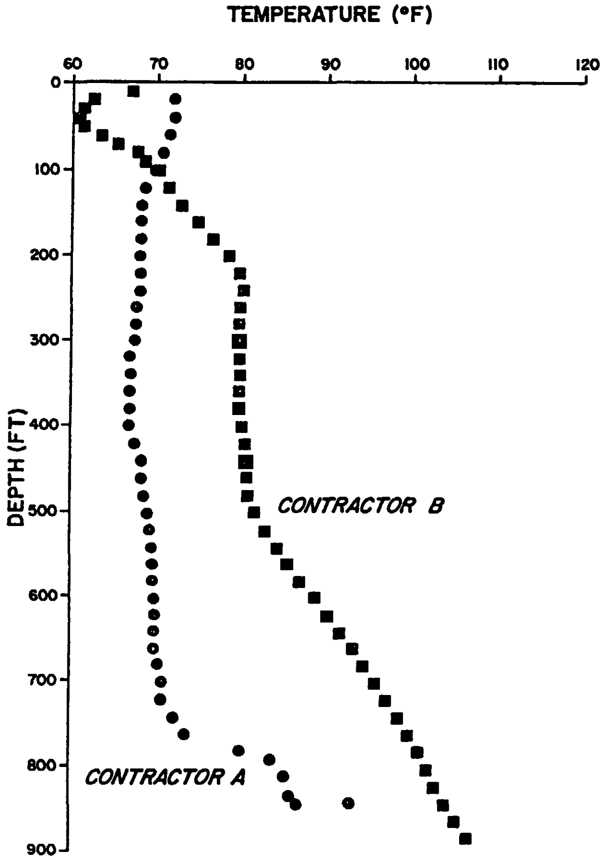

FIGURE 5: Repeat "stabilized" temperature profiles in the same temperature gradient hole obtained by two different vendors.

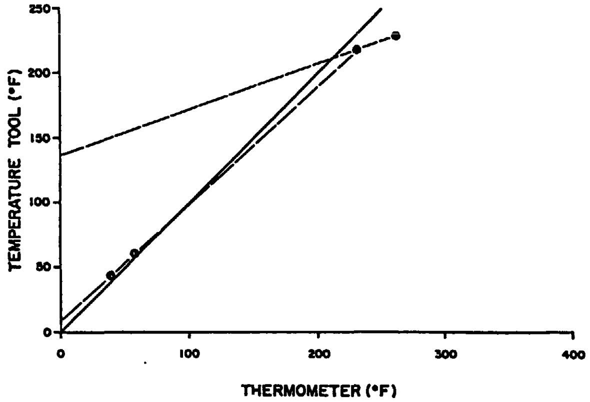

FIGURE 6: Field calibration check of a temperature tool, indicating non-linear calibration.

A second approach to the calibration problems illustrated by Figure 5 is to develop internal temperature tool calibration facilities. The pressurized temperature calibration facility, shown schematically in Figure 8, was developed for in-house temperature tool calibration. This calibration facility allows detailed calibration of temperature tools, as shown by Figure 9.

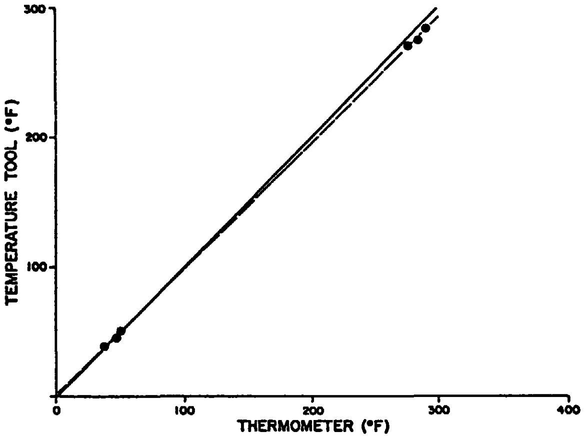

FIGURE 7: Field calibration check of a temperature tool, indicating linear calibration.

The above examples illustrate client-vendor cooperation to improve logging measurement quality. I have always found wireline vendors open and willing to make such improvements. another approach to wireline quality control is to do the work yourself. This

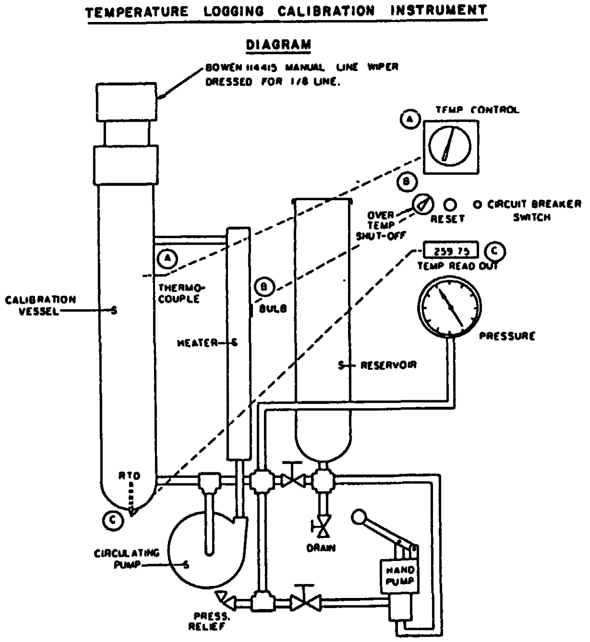

FIGURE 8: Schematic for shop temperature logging tool calibrator.

is not something that I recommend. First, there is the initial cost of purchasing the equipment. Then, there is the cost of training and, in some cases mandatory, licensing of personnel to operate it. Finally, there is the cost of continuous maintenance and calibration.

It is extremely difficult for a geothermal developer to justify an in-house wireline unit on the basis of cost-effectiveness alone. Generally, it is much more practical for the developer to work with the vendor to maintain product quality and let the vendor distribute the costs of maintaining the wireline units among all of their clients.

Horner extrapolated and measured stabilized temperature profiles from an intermediate depth temperature/gradient borehole in western Nevada. The exploration model for this prospect predicted 175° F at a depth of 1500 ft. The Horner extrapolated temperature profile predicted just under 150° F at that depth. The final stabilized temperature profile, while higher than 150° F, at 1500 ft, was closer to 150° F than 175° F.

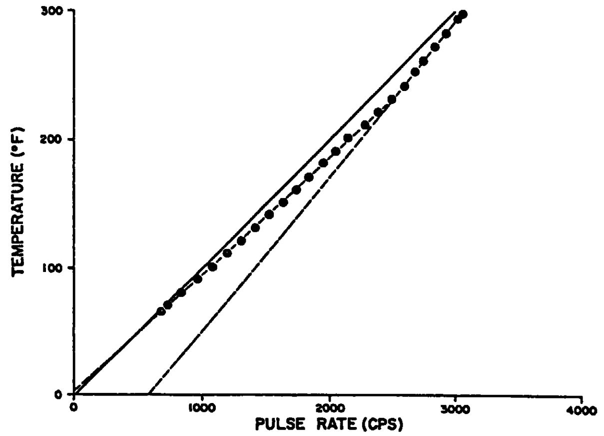

FIGURE 9: Detailed temperature logging tool shop calibration.

RAPID EVALUATION OF GEOTHERMAL PROSPECTS, USING HORNER PLOT TEMPERATURE EXTRAPOLATIONS

Horner temperature build-up plots (Dowdle and Cobb, 1975; Horner, 1951) offer a simple and rapid method of evaluating the temperature regime of a geothermal well before it is cased (Hill, 1993). Figure 10 shows measured,

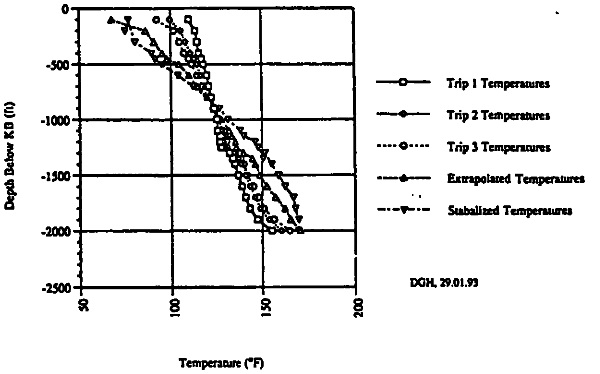

FIGURE 10: Measured, extrapolated, and stabilized temperature profiles from a single well.

PROTECTING WIRELINE TOOLS FROM THERMAL SHOCK

Commercial geothermal reservoir temperatures are above the safe operating temperatures of all but 'hostile environment' wireline tools. To be able to use conventional and slim-hole wireline tools, the borehole must be cooled below the safe (logging tool) operating temperatures for the entire logging operation.

Drilling the borehole has already cooled the borehole somewhat. The borehole can be further cooled by extending the pre-log well conditioning circulation period. The question remaining is how long should the well be circulated?

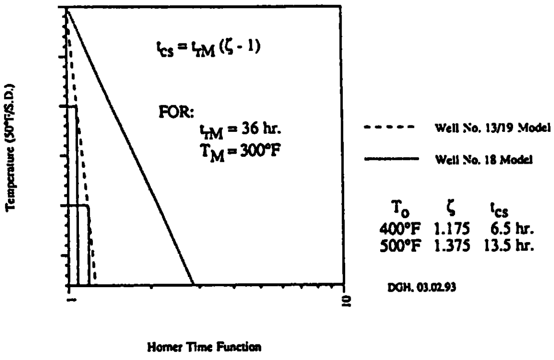

FIGURE 11: Example of predicting circulation times to protect logging tools from thermal shock.

A variation on the Horner plot offers a solution. Figure 11 shows a Horner plot grid with two temperature build-up models for a site in eastern Nevada. This display is analyzed to estimate how long a well should be circulated, for assumed reservoir temperatures of 400° F and 500° F, prior to initiating a 36 hr logging operation with wireline tools having safe operating temperatures of 300° F. The resulting circulation times are 6.5 hr for a 400° F reservoir and 13.5 hr, for a 500° F reservoir. Choosing the optimistic reservoir temperature (500° F) and adding a little cushion, would yield a circulation time of two tours (16 hr). This approach to estimating pre-logging circulation times has proven to be very successful in avoiding wireline tool burn out.

PITFALLS

Successful use of this phased geothermal development approach, however, requires considerable discipline. There is a great temptation to cut costs and accelerate development by omitting steps. Succumbing to this temptation is short sighted. Siting a commercial geothermal well is a significant capital expenditure. A inappropriately sited well could severely hinder, if not outright kill, development of a geothermal property. Even if a miss-sighted well can be overcome, the omitted development steps must be completed prior to sighting a second commercial well. The real costs of prematurely, and consequently miss-sighting a commercial geothermal well are both financial and time consuming.

CONCLUSIONS

The use of a three phase geothermal drilling program of successively deeper temperature/gradient boreholes is a cost effective method of evaluating geothermal properties prior to drilling commercial wells. Wireline measurements of intermediate depth temperature/gradient boreholes provides structural and physical property control for interpreting surface geophysical measurements. Successful use of this approach, however, requires discipline not to accelerate development by omitting steps.

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