DRILLING GEOTHERMAL WELL ISO

Prepared for
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INTRODUCTION

This report was prepared for Mr. Dale Merrick of I'SOT, Inc. to document the process that led to drilling and completion of their geothermal well ISO-1, located in Canby, Modoc County, California. The drilling project was completed during the months of April, May and June 2000. Construction of the well was partially funded by USDOE, and partially by I'SOT, Inc. This report does not include analysis of well testing data.

The report was prepared from the author's notes taken while being on site, and notes taken from phone reports by Dale Merrick and daily driller's reports. The purpose of this report is to document and analyze the data and document what has been learned from this project.

DRILL SITE LOCATION AND FEASIBILITY ANALYSIS

As is typical in such projects, the drilling site had to be selected based on practical considerations dictated by the infrastructure of the I'SOT property. An empty lot was selected, large enough to accommodate all drilling equipment, and close to the facilities that would eventually be served by the well. Subsequent aerial photo analysis hinted at the presence of a lineament in close proximity to the well site, thereby verifying the suitability of the selected site.

Feasibility of the drilling project was based on an earlier analysis by the Geo-Heat Center, assuming a depth to reservoir of 1,600 ft, based on the data obtained in the 1970s from the Kelley Hot Springs Area (KHS), located less than two miles to the east.

For the purpose of permitting and bidding, a synopsis of geologic and hydrogeologic information pertinent for this drilling project was prepared. Pertinent reports and drillers logs were reviewed to determine if:

- Water quality expected would be suitable for disposal either in a wetland or the nearby Pit River,
- The desired temperatures can be found within the proposed target depth of 1,600 ft, and
- That depth can be reached with the proposed drilling budget.

A number of reports were reviewed, copies of which were obtained in 1990 from the State Division of Oil, Gas and Geothermal (CDOGG). Most of the data were drawn from a report prepared by GeothermEx for Thermal Power Company, dated March 1977. Other information included a report prepared by Eliot Allen (1986), local driller's logs, and a number of chemical analysis data sets. Much of this effort also benefitted from what had been learned in the late-80s and early-90s in the Alturas and Bieber drilling projects (PGH, 1992, GJ&A, 1987 and others).

Given the limited budget, no additional field work was conducted to gather additional data.

Based on data from the Kelley Hot Springs wells and the Alturas, California city wells, the proposed well was anticipated to be flowing artesian, producing out of fractured lithified tuffs. Although the initially proposed target depth was 1,600 ft, it was recommended to plan for a minimum target depth of 2,000 ft, to assure flexibility to accommodate unforeseen cold water zones above 1,600 ft, and the uncertainty of finding a water bearing zone at 1,600 ft. More so it would have provided for sufficient resources to drill to an aquifer that was at a temperature similar to the minimum observed in the KHS wells.

GEOLOGIC CONDITIONS AT DEPTH

Based on geophysical, geochemical and drilling data, previous investigators concluded that the Kelly Hot Springs area, including Canby is underlain by an extensive geothermal aquifer below 1,600 ft, reaching down to more than 3,000 ft (GeothermEx, 1977). For example resistivity data suggest a low resistivity area extending several miles across Warm Springs Valley from east to west.

In the 1970s, at least two deep wells were drilled near Kelley Hot Springs to depths exceeding 3,000 ft. The wells were drilled in the 1960s and 1970s, by GRI and GPC. These bore holes penetrated clays, silts, sands and gravels and their lithified equivalents, plus intermittent basaltic lava flows. Apparently the lithology extending east from KHS is relatively consistent, and was assumed to be similar at the proposed drilling location to the west.

The temperatures encountered by the KHS exploration wells were measured at 239ºF maximum. This temperature prevails below 1,600 ft down to more than 3,000 ft. Temperature gradients in several shallow temperature gradient holes near KHS were more than 30ºF per 100 ft.

The area where drilling was proposed as part of this project has higher resistivity at depth, which could be indicative of geothermal water diluted by river water, or a lower permeability zone. This may have affected the success of this well, symptomized in somewhat lower temperatures and greater depth to a production zone.

In previous years, a number of wells were drilled near the I'SOT geothermal well location, but these wells do not exceed 900 ft. Geologic conditions below that (i.e., down to the proposed target depth of 1,600 ft, or deeper) were extrapolated from the deep wells drilled near the Kelley Hot Springs (KHS), and from the two temperature logs prepared by Eliott Allen and Associates in 1984.

Gradients observed in the nearby Canby School Well No. 1 were up to 7ºF per 100 ft, similar as in the nearby I'SOT test well drilled in 1985 (Eliot Allen, 1986). Assuming a surface temperature of 58ºF and a gradient of 7ºF per 100 ft, the proposed well was expected to reach a temperature of 170ºF at 1,600 ft, assuming no major shallow aquifer(s) had to be penetrated before target depth.

The temperatures encountered by the KHS exploration wells were measured at 239ºF maximum. This temperature prevails below 1,600 ft down to more than 3,000 ft. Temperature gradients in several shallow temperature gradient holes near KHS were more than 30ºF per 100 ft. However, given the data from Eliot Allen & Associates (1986, p. 75) from the I'SOT well, the temperature is more likely to be about 150ºF.

DRILLING HISTORY

The drilling history is summarized in the Table 1. The well was spudded on April 3, 2000. The contractor was Story Drilling Services (SDS) of Klamath Falls (selected by bidding).

Although initial drilling progress was reasonably good below about 400 ft, drilling progress slowed down significantly due to the sticky clay (fine-grained tuffs) formations, eventually forcing the driller to drill with a blade auger bit. This problem, from the start, severely affected the course of the drilling project, and added to the project's continuing budgetary problems.

On May 4, when the hole had reached a depth of 900 ft, a temperature log was conducted. The results were encouraging, suggesting a gradient of about 7ºF per 100 ft, as predicted. Although the gradient observed in this log was still affected by previous drilling mud circulation, the observed temperature of 110ºF at 850 ft reasonably well matched the expected temperature of 150ºF at 1,600 ft (assuming a gradient of 7.14ºF per 100 ft). In other words, up to that depth, the temperature gradient was as expected. Assuming a desired resource temperature of 160ºF, it was expected the target depth would still be 1,600 ft to obtain such a resource (assuming there would be a water bearing zone at that depth). By May 11, a depth of 1,599 ft was reached. Although the original target depth had been reached, no water bearing formation was encountered and a decision had to be made whether to drill deeper. At this time, another temperature log was run. The results of this log were disappointing. However, given the fact that the lithology had not changed significantly since 850 ft, it was assumed that these results were affected by inadequate temperature equilibration following mud circulation. However, given the financial commitment made so far, the operator felt uncomfortable stopping short of a major resource. For that reason, it was decided to allocate more financial resources and to continue drilling until a resource was found. Under the given gradient, assuming a minimum reservoir temperature of 125º F, the operator felt it was worth continuing drilling until a resource was found, presumably above 2,300 ft.

Given continuing concerns about potential sloughing problems after more than five weeks of drilling, it was decided to set and cement 6 5/8- inch casing (0.250" wall strength) to 1,600 ft before continuing with drilling. The casing string included a 10-inch diameter pump chamber (10 ¾-inch OD, 0.280" wall) from surface to 251 ft, connected to the 6-inch casing with a bell reducer.

Drilling continued with a 5 7/8-inch bit. By May 31, a depth of 1,952 ft had been reached. Although still no significant change in lithology was encountered, increasing occurrence of partially lithified tuffs below 1830 ft. An important observation was a red zone of lithified fine-grained tuff at about 1,950 ft, suggesting maybe a fault zone.

On June 5, another temperature log was conducted. A bottom hole temperature of 208ºF was measured at 1,908 ft with a maximum mercury thermometer. The decrease of the temperature gradient below 1,830 ft (obtained by Wellenco), was encouraging, suggesting a change in formation characteristics, maybe associated with some fracturing.

By June 8, the hole had reached 2,100 ft--the maximum depth the contractor could drill to (due to limited drill pipe availability). At 2,048 ft, the hole began to lose mud circulation, requiring addition of about 20 to 25 gpm of water (plus bentonite) for more than six hours (i.e., the total amount of drilling fluid lost was about 7,500 gallons or more). Caliper and electrical logs run to 2,100 ft were encouraging, suggesting a significant water bearing zone below 2,075 ft. After the hole was cleaned out, a 4-inch liner was set from 1,531 to 2,100 ft, with perforations from 1,900 to 2,100 ft (3/16 in. by 2.5 ft, eight slots per foot).

Subsequent well development showed disappointing results, and was hampered by the drill rig's inability to airlift more than 500 ft of water column to flush out the perforations and/or fracture. Several options were considered, including sounding the well to determine if cuttings had filled the hole, and then clean out the well with a cable tool rig with a 2,100 ft sand line or a larger air compressor and small diameter tubing.

Given the unobstructed installation of the liner, liner perforations being obstructed by cuttings was deemed unlikely by the driller. Instead it was assumed that the fracture was plugged by drilling mud and/or cuttings. On June 15, under directives of Ed Granados of Geothermex, Inc. (the consultant working for SDS), the driller started to inject cold water into the well, to flush out and dilute any remaining mud deposits that would inhibit production of the well.

Unfortunately, after more than four days of injecting between 250 and 350 gpm at about 230 psi pressure, the hope for decrease in injection pressure never occurred. Consequently a sinker bar was lowered to the bottom of the well, which suggested that the well had filled up below 1,973 ft.

To clean out the fill SDS leased a high yield compressor and 2,100 ft of small diameter tubing, attached to the drill string (small enough to fit inside the 4-inch liner

Table 1 - Geothermal Well ISO-1, Drilling History	
4/3/00	Start drilling project: drill 12 1/4” pilot hole to 275’.
4/4 - 4/5	Ream to 18” diameter to 260’. Run 14” casing to 257’.
4/6/00	Pump cement, cement surface casing.
4/10-4/12	Rig up BOPE.
4/12/00	Pressure test BOPE. Tag cement at 220’. Drill out cement to 256’.
4/13-4/17	Drill with 9 7/8” bit to 495’. Drilling progress slowed due to clay rich formations.
4/17-4/23	Change to long tooth soft formation bit for clay formations. Drill to 709’.
4/24-5/2	Due to repeated problems with clay plugging long tooth tricone, changed 9 7/8” drag bit. Changed out drill bit at 895’, due to problems with changing formation from clay to lava. Then back to blade bit.
5/3	Pull drill string, lay down. Ready the hole for temperature log.
5/4/	Run temperature and caliper logs to 895’ by Geo-Hydrodata. Then trip back in.
5/5	Drill to 1411’ then change to mill tooth bit.
5/11	Drilled to 1599’. Temperature and caliper logging by Geo-Hydrodata.
5/12	Decision made to continue drilling.
5/14-5/25	Run 6” casing to 1599’, and cement casing, with Haliburton Co.
5/26-5/31	Tag cement at 1500’. Drill out of casing, drill to 1952’. Below 1830 ft increasingly partially fine-grained lithified tuffs are observed.
6/5/00	Down hole geophysical logging, temperature, caliper logs. A bottom hole temperature of 208F was measured 1908 ft. Temperature gradient approximately 7.5F/100ft.
6/2 - 6/8	Continue drilling to 2100 ft.
6/13 - 6/15	Run 4 inch liner from 1600’ to 2100’, with perforations from 1900 to 2100 ft.
6/15 - 6/30	Attempt to clean out fracture zone by injecting cold water. Subsequently clean out obstruction (drill cuttings) from below 1973 ft, and develop the well.
6/30	Drill rig released.

below 1600 ft). On June 28, the driller started airlifting the well, slowly lowering the open end of the tubing to the depth of the obstruction. By June 30, the well had been cleared, producing about 75 gpm at 140 to 158°F by airlift. The material lifted to the surface turned out to be angular and sub angular chips of lithified tuff (i.e., drill cuttings) presumably washed in from the fracture and/or the annulus between formation and blank liner.

The drill rig was released on June 30.

GEOLOGIC SECTION

The geologic section is made up almost entirely of unconsolidated fine-grained tuffs. One exception was a “lava flow” between 890 and 900 ft depth. The lithologic log is summarized in the Table 2.

Table 2 - Geothermal Well ISO-1, Canby, Modoc County, CA. Geologic profile: (sample depths indicated in left column)	
10 to 40 ft:	Soil and alluvial deposits.
50 to 70 ft	Fine-grained tuff
80 to 180 ft	Lacustrine gravels, mixed with fine-grained tuffs.
190 to 590 ft	Volcanic mud flow
600 to 660 ft	Fine-grained tuff, partially lacustrine deposits.
670 to 780 ft	Volcanic mud flow, probably lacustrine deposit.
790 ft	Lithified fine-grained tuff.
800 to 880 ft	Volcanic mud flow. Rock fragments, embedded in greenish-grey clay often rounded, coated with white non-carbonaceous mineral deposits (alteration)
890 ft	Lava, probably andesitic (less than 10 ft thick)
900 to 1380 ft	Volcanic mud flow: greenish gray clay with subrounded and angular rock fragments. Slightly altered.
1390 ft	Fine-grained tuff, partially lithified.
1400 to 1600 ft	Volcanic mud flow.
1610 to 1620 ft	No samples
1630 to 1680 ft	Lacustrine sand: fine to very fine sand, angular zeolite crystals, and rounded rock fragments.
1690 to 1870 ft	Fine-grained tuff (maybe occasionally lithified?)
1880 1930 ft	Lithified tuff. Angular chips, of indurated (cemented) fine-grained tuff.
1940 ft	Red tuff, fine-grained. Poor sample recovery. Sample recovered from drill bit, suggests fine-grained tuff.
1950 to 2040 ft	Angular chips of fine-grained lithified tuff, embedded in reddish brown clay (tuff).
2050 to 2100	Chips, angular and sub angular, of fine-grained tuff embedded in dark gray clay. Sample from 2090 almost purely chips, no clay. Chips show evidence of fractures, lined with pyrite and reddish-brown material, and white to greenish white deposits. Sample from 2100 has again reddish brown clay matrix.

Figure 1. Drilling rig setup.

Figure 2. Blowout preventor being installed.

Figure 3. Cementing operation.

Figure 4. Drilling bit with clay.

Figure 5. Compressor for blowing out the well.

Figure 6. During air stimulation.

To summarize, several general observations can be made.

Lithology

The sequence of geologic formations consists almost entirely of fine-grained tuffs (volcanic ash) and lahars (volcanic mud flows). The monotonous clay rich profile is broken up only in two cases:

- A thin lava flow (less than 10 ft thick) between 890 and 900 ft, which is probably andesitic, and
- A lacustrine sand layer (probably of volcanic origin) between 630 and 1,680 ft.

The fine-grained nature of the tuffs and lahars is symptomized by the predominance of sticky gray-green clays, which made drilling rather difficult and added to cost overruns.

The entire section is believed to have penetrated the lacustrine and volcanic sequences of the Alturas Formation. As was the case in both Alturas wells (AL-1 and AL-2) and the Bieber well, production in the ISO-1 well is from fractures within lithified tuffs below 1,950 ft.

Alteration

Alteration (changes in mineral composition due to elevated temperatures) is evident throughout the entire profile below 500 ft (if not 200 ft), as symptomized by occasional silicic coatings on rock fragments, mineral deposits on vugs lined with mineral deposits, and frequent greenish staining of light colored rock fragments. In general, the "clays" (fine-grained tuffs) appear to be greenish in many sections, suggesting chloritization, which is an indication of alteration.

Production from Lithified Sections

In Alturas and Bieber the fractured lithified sections tended to produce hot water instead of fractured lava flows. Above 1,830 ft, the almost continuous sequence of fine-grained tuffs (symptomized as clays) in the ISO-1 borehole is characterized almost completely by the absence of what could be clearly interpreted as lithified sections that could produce water. However, the section below 1,830 ft contains increasing evidence of lithification, and the section below 1880 ft is even more lithified. Below 1,950, the fine grained tuffs are probably entirely lithified. Though only very rarely, these lithified sections show occasional evidence of hairline fractures filled with mineral deposits.

Below 1,940 ft, the cuttings are characterized by fine-grained red tuff (a sample recovered from drill bit, suggests fine-grained tuff). Below 1,950 ft, the predominance of angular chips, and reddish brown clay (tuff) suggests an almost completely lithified fine-grained tuff. Chips from this section were typically angular and sub angular. Occasionally the chips show evidence of fractures, lined with pyrite and reddish-brown material, and white to greenish white deposits.

For clarification, the term "lithification" suggests grains being cemented together by mineral deposits in the microscopic pore spaces. These mineral deposits originate probably from water trapped in the sediment for extend periods of time at elevated temperatures. Evidently lithification occurs to a higher degree below 1,950 ft.

The increasing lithification in the lower ISO-1 borehole is encouraging from a standpoint of producing water. It is possible that below 2,100 ft, the degree of lithification may increase; gradually, leading to harder formations that are even more promising for holding open water producing fractures.

Comparison with Kelley Hot Springs Geologic Logs

This geologic profile matches only to an extent with the one described for the Kelley Hot Springs wells. Both the KHS and ISO-1 wells are similar in that they both intercepted a very thick sequence of fine-grained tuffs, which are in part lithified.

But, there are also some major differences. For example, while ISO-1 encountered only one thin lava flow at 890 ft, at Kelley Hot Springs at least five "basaltic lava flows" were logged between 364 and 1980 ft, ranging in thickness between 10 and 260 ft.

One lava flow logged at KHS as "granodiorite" between 1,088 and 1,148 maybe equivalent to the lava flow logged between 890 and 900 ft in the I'SOT well (which in our opinion is probably andesitic, considering that granodioritic intrusives are absent in this part of the Modoc Plateau).

The KHS geologic logs also show several inconsistencies. For example it repeatedly mentions what is commonly referred to as "shale" by many drillers. These are probably lithified fine-grained tuff, the kind of formation that was also encountered below 1950 ft at ISO-1. Interestingly the KHS records indicate that production is commonly associated with these lithified tuffs, as was observed in ISO-1.

SYNOPSIS

A number of conclusions can be drawn based on the results of this project. This brief discussion will address three subject matters: geologic model, budget and project management.

Geologic Model

Evidently, ISO-1 barely penetrated only by about 200 ft into a much larger geothermal resource at depth. Although the lithified tuff sections were encountered at a depth similar as in Alturas, it is certainly deeper than at Kelley Hot Springs. This may very well explain the increasing resistivity around the ISO-1 site, as mapped in the 1970s. Although the final temperature estimate at bottom hole is still not determined, it is clear that the temperature is at least close to the minimum temperatures observed at KHS. It is likely that if ISO-1 had been drill only a few hundred feet deeper a much better well would have been completed.

All three intermediate temperature geothermal drilling efforts in the eastern Modoc Plateau (Bieber, Alturas and Canby) suggest a number of common features:

- Production zones are associated with lithified tuffs. These seem to occur at depths not shallower than about 1,800 ft,
- Temperature gradients above the lithified zones are about 7°F per 100 ft, suggesting formations with very similar thermal properties (confirmed by the geologic logs), and
- Given the similarity in depth and gradients, the reservoir temperatures must be similar in all three areas.

These observations may lead a number of conclusions that should be considered in future drilling efforts in the deep sedimentary basins of the Modoc Plateau:

- When planning a drilling project one should assume that the target depth is about 2000 ft or deeper.
- At that depth the resource temperature is probably greater than 185°F, if not more than 200°F.
- Assuming a conveniently lower resource temperature to accommodate a lower drilling budget is probably not warranted.

Project Management and Budget

The project budget clearly affected the outcome of this project. Although the Alturas drilling experience had clearly suggested that it is best to use a large rig, instead of a common water well rig, the budget realities for this project led to using a much smaller (water well) drilling rig.

Unfortunately, not having enough information at hand the initial proponent of this project was not able to develop a realistic budget. The initial bidding process had made it clear that, among other items, mobilization costs would lead to significant cost overruns. The larger drilling companies are located in Reno and the Sacramento area, if not southern California, which significantly increases mobilization fees. Preliminary cost estimates from qualified drilling consultants suggested that the cost for this well would be more than $200,000, using a rig comparable to the one used at AL-2 in Alturas. During the bidding process this estimate was confirmed by the bigger drilling companies, although at least one local small water well drilling company was able to bid within the desired price range.

Unfortunately, contracting with a smaller rig turned out to be as costly if not more costly than using a large rig, due to slow drilling progress in the clay rich formations. Slow drilling also eventually resulted in the hole becoming unstable, forcing the driller to run casing too early, thereby limiting further drilling options at greater depth. Clearly this affected the ability to drill to sufficient depth (and eventually well productivity). For example, instead of the anticipated three weeks, it took almost three months to drill ISO-1 (and AL-1 in 1987); while, it took only 11 days to drill AL-2 (in 1991) to almost the same depth. Evidently, being able to generate higher mud pressures, a larger rig is more capable of dealing with these difficult drilling conditions in the clay rich formations, than a small one.

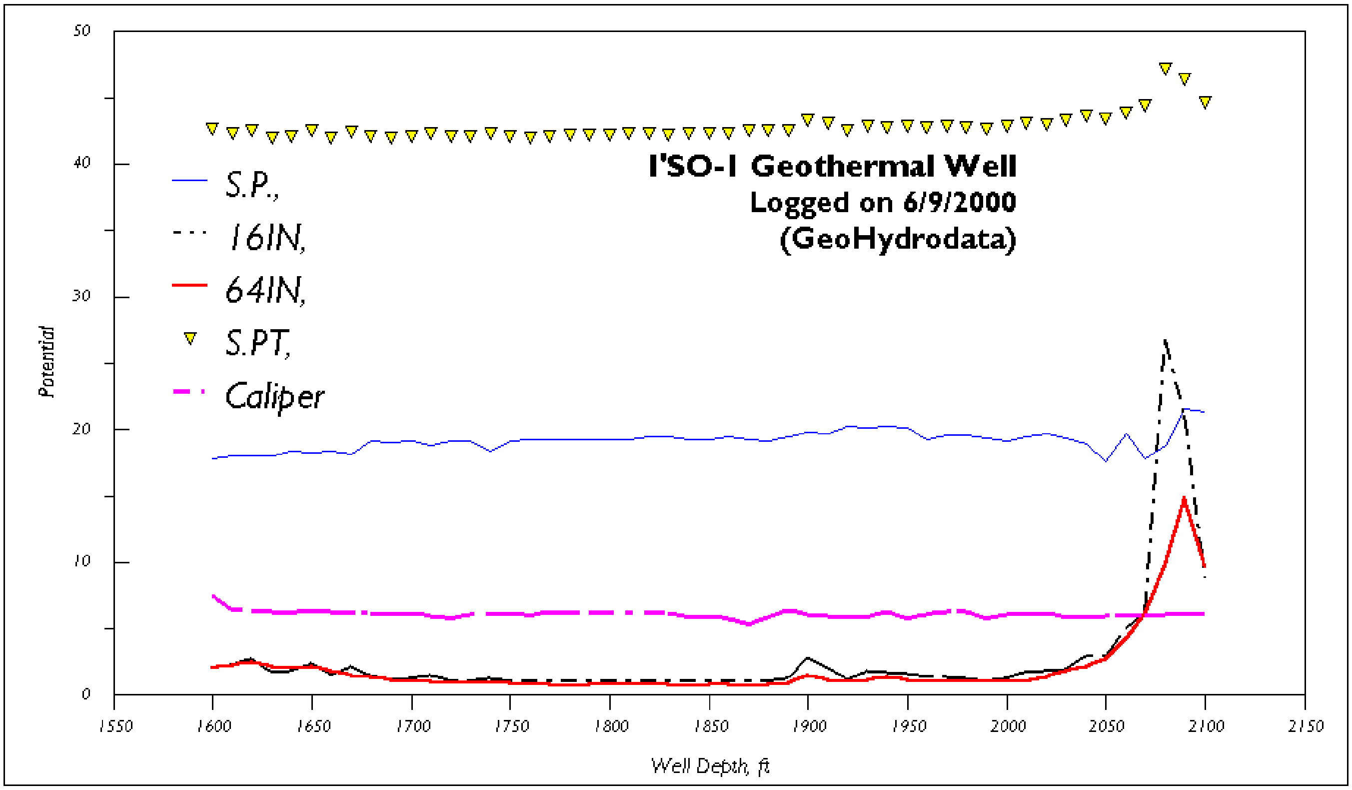
The trouble is that these problems are only symptomatic of a much larger problem that is related to the initial project budget planning. In the case of ISO-1 an insufficient budget (funded by a federal grant) forced the operator into making adjustments in the drilling program, overly optimistic assumptions and greater financial commitments than originally intended. To worsen matters, due to a policy decision at the state level, the operator was forced to quickly come to a drilling decision, or otherwise jeopardize California State (CEC) funds made available for retrofitting the heating system above ground. Not having more time, the operator was not able to secure further funds for the project before the drilling started. Fortunately for this project, the operator was determined enough to pull through to the end and borrow money against equity to bring the project to fruition. Our common experience is that drilling usually takes more money than most people think, and if not enough money is committed to begin with all money spent maybe wasted. Worst of all is when operators and drillers are forced into risky "cost-saving" measures which usually in the end come to haunt us by leading to even greater costs.

Once drilling started the commitment was made, and the operator was forced to pull through, or otherwise lose not only the funding for the retrofit, but also having wasted their matching funds already provided out of pocket. Sadly, any drilling project that falls short of the minimum drilling target based on technical analysis, leads to a waste of significant amounts of government and private money.

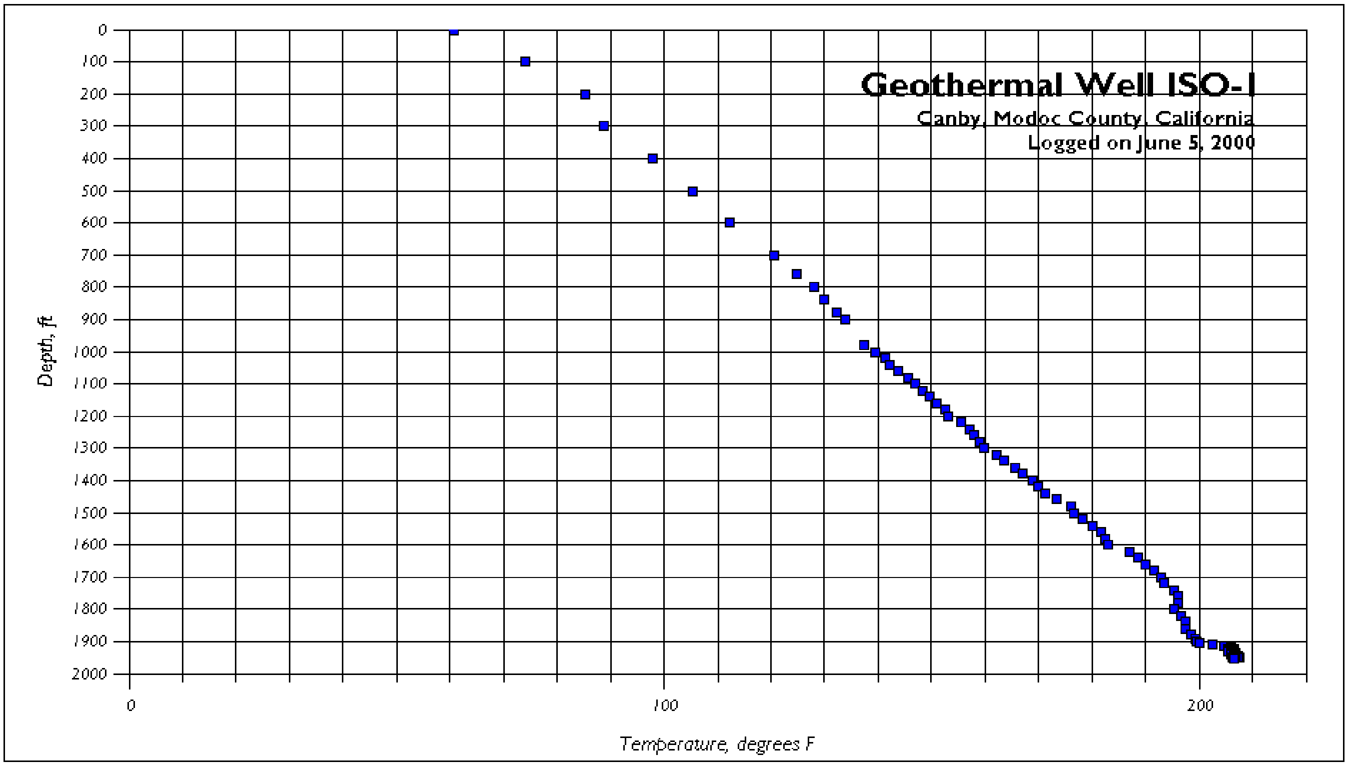
These observations symptomize what has been said before. In the 1980s, the author of this report was involved in several geothermal drilling projects in northern California. It was observed already then that the funding agencies funded too conservatively. It led several drilling projects to be conducted only to find that they had to stop short of reaching a good resource. Often, this occurred when being within reach of only several hundred feet of the target depth. This was the case in the Bieber drilling project (Lassen County), the Clio and Indian Valley Hospital drilling projects (both in Plumas County), and it almost happened in Alturas. In the latter a reasonable drilling budget was put together by merging two separate drilling projects (each one under budgeted) thereby eventually leading to one successful well, AL-1.

Sadly, in at least one project (Clio) the failed drilling effort led to the probably unwarranted conclusion that there is no resource, although the geophysical and geochemical data analysis came to rather optimistic prediction.

The lessons learned should be heeded for future funding of geothermal drilling projects in the Modoc Plateau. It maybe advisable that funding agencies base their funding allocations on an independent and in-depth geologic and budgetary analysis of the proposed project. It is important that project management and well testing receive sufficient contingencies (in our experience drilling decisions should not be left entirely to a drilling contractor, but to a well balanced, constructive decision making process shared by driller and geologist). After all, too many promising drilling projects have turned into failures not because of a poor resource, but



Caliper Log and Electric Logs



Temperature Log

because of budget troubles. Not enough money spent on a promising project without fruition, is money spent without benefit, whereas when an adequate amount of money results in a successful project, it can be easily justified by its own success story.

RECOMMENDATIONS

The immediate recommendations made for this project are:

- The well should be tested to determine long term production capacity. This would be best accomplished with a constant discharge test, following a short step drawdown test. The constant discharge test should be long enough until the data convincingly plot as a straight line on a Cooper-Jacob plot (which may take up to a week or more).
- Water quality testing should be done during the latter half of this test. We also recommend to have a sample analyzed for stable isotopes to be able to compare this well with other geothermal waters in the Modoc Plateau (including Kelley Hot Springs).

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