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GEOTHERMAL DRILLING EFFECTIVENESS

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ABSTRACT

The subject of cost of geothermal drilling and risk often comes up and how it can be minimized. The reason is that for power projects the cost of drilling geothermal wells for production or reinjection is about 40% of the projects total investment. Half of the drilling cost then again comes from the rental of rigs and services (day rates) and the other half is from materials and infrastructure. The wells are typically drilled in anywhere from 30 to 60 days and thus the effectiveness, or speed of drilling, impacts greatly the cost. This can be analysed by comparing the results for wells within the same field and to some extent between different areas or parts of the world. The International Drilling Contractor Association (IADC) Standard Daily Drilling Report Form contains a break-down of the time spent on different job categories according to Key Performance Indicators (KPI). There are other Benchmark metrics that can be applied to select operations to identify the drilling performance. Such comparisons aid in identifying problem areas and the level of risk. The paper describes the results of a MS thesis from 2010 by Björn Sveinbjörnsson where the drilling performance of 50 HT geothermal wells in the same field in Iceland was analysed and the statistical level of risk assessed. The number of working days to complete each depth section of the well (4 sections) and the time was then broken down to show how much was spent on drilling, tripping, casing, cementing, logging etc. The results were then grouped according to which design was used and technology applied. Cost calculations were made, based on market prices, as the as the real cost was not made available. The time break-down had similarly to be worked out from the geological reports as the KPI data was confidential. Where there were more than three standard deviations (3 sigma) in the time for any one section of a well the causes were identified. The results showed that 19 % of the wells had such problems, the main cause due to geological risks mainly getting stuck in the hole. Comparing the drilling effectiveness between Regular Diameter holes (w/ 9 5/8" production casing) and Large Diameter holes (w/ 13 3/8" casing), it is interesting to note that the larger wells took slightly less time to complete. Other comparisons made were for: vertical vs. directions wells, drilling with water only or managed pressure drilling by aerating the water. Finally the success of the drilling effort was assessed in terms of well output (MWe), as this affects the overall project economics even more than the cost of drilling. For success metrics, comparisons were made between the Injectivity Index (II) at the end of drilling and the confirmed flow-output (MWe or kg/s of steam and water) of the well. How the final output related to the type of well design and drilling technology applied, was also assessed. There was not a clear "winner" in this category, as the average well output was roughly the same or 5.7 or 5.8 MWe. The output from well to well, however, is quite different, mainly determined by the reservoir conditions, as the temperature and permeability varies considerably over the geothermal field in question. A reference case was set up for a 2175 m deep directional well with large casings and a cost estimates prepared. This took into consideration the statistical results, by use of the Monte Carlo method. A similar time study, as a part of a larger report, was made by Thomas Miyora Ongau, a UNU Fellow in 2010. It compared the time analysis from 12 directionally drilled geothermal wells in Kenya to 14 wells in Iceland of similar design. There were no major differences in the overall results but time spent on separate activities differed and the causes were identified.

1. INTRODUCTION

A lot of information is gathered and reported for all phases of geothermal development. The proper handling of all of this has become easier in the digital age, but partly as a consequence it has also increased the amount of information and what is required. This paper aims to show that processing of such data, for example from the drilling effort, can lead to better understanding of the drilling risks and how to meet them. The term "drilling efficiency" relates to performance of the drilling operation and its outcome on a broad scale. There is now an acceleration of geothermal drilling activity worldwide and as more data is generated the question becomes how to make use of it for decision making, obtaining better result and estimates and ultimately to lower the costs.

The drilling reports deal with the drilling program, design and targeting, numerous daily drilling reports, e.g. Standard Daily Drilling Report Forms and separate ones from all the contractors engaged on the rig. Then there is technical documentation for the equipment, materials and safety and recommended practices, regulations and compliance/inspection reports for HSE. After the rig is released well logging and output testing is reported. There are memos of meetings and e-mails etc. to be filed. Additionally there is all the logging data from the mud logger drilling rig instruments and down-hole logging tools, presented in figures or in digital files. All this data is filed away on computer systems and is made available to selected groups of persons, according to the need to know. Integrated data storage and reporting programs are available in the oil industry that have also been applied for geothermal operations, but due to the geothermal operators small size operations, many still rely on standard data bases for storing the digital data and on collaborative software programs to store the reports. All of this is set up differently in each organization, according the IT set-up and project management procedures.

The daily reports and well completion reports are the focus of this paper, providing the time vs. depth information and time breakdown. Such information is found in the IADC Standard Daily Drilling Report Forms. These forms or "Tour Sheets" are near universally being applied to drilling projects. The entries are hand written in the respective box and now electronic forms are also available. There are 6 software companies exclusively authorized by IADC to use their format. One drilling information software package in particular is widely used by geothermal drilling contractors. It integrates a lot of drilling information and produces the standardized reports. Time duration of each activity (hr) is reported with a corresponding IADC Key Performance Indicator (KPC). One of the programs feature is KPI analysis for one well or between several. Time vs. depth information can also be gleaned from the Geologist Daily Report or from the Mud Logger, but is not as exact.

The information about the drilling performance of each well is usually summarized at the end of drilling in figures plotting the depth vs. working days and the KPI analysis in pie-chart or bar-chart graphs. All performance or cost information is treated as confidential by the companies involved and therefore there is a dearth of information in open geothermal literature. There have been several initiatives, both national and international, to analyze the cost of drilling and identifying ways to cut it. Due to reluctance to share information the data in the open data is mainly derived from government supported projects, where obtaining research data was the primary goal. Such wells do not necessary reflect the performance results one can expect from routine production drilling of many wells without interruption. The following two chapters will provide a summary of findings from two recent student reports. The case stories are from projects where many similar geothermal wells have been drilled. Additional metrics can be applied, so these results should only be viewed as examples of what may be achieved.

2. ANALYSIS OF 50 HT WELLS DRILLED IN THE SAME FIELD IN ICELAND

2.1 Time study

The quickest way to gauge the drilling performance or effectiveness of a well, is to view the progress graph, depth vs. working days, found in all drilling or geological reports. The first thing to look for is the number of days the drilling took and then the number and duration of so called “flat spots” where there is no advance in depth. So-called “flat spot analysis” is to identify what the problems were. The total number of days is an indicator of the well cost (for wells with a day-rate contract). For geothermal wells drilled in Iceland, however, there is an integrated drilling contract based on meters drilled (cost per meter) and fixed unit prices for materials and certain operations. These are obtained by international tendering. All services are under one contract. Turn key contracts based on meter rates are possible where the conditions are fairly well known and involving drilling a good number of wells, 20 wells under the same contract in this case.

The two casing designs used are typical of geothermal wells drilled worldwide, either: a) Regular Diameter wells with 9 -5/8” prod casing, b) Large Diameter wells with 13 3/8” prod. casing. For both there are three cemented casing strings with roughly the following depths: surface to 90 m, anchor to 300 m and production casing to 800 m and then there is a slotted liner to total depth. The early wells were drilled vertical and are of Regular Diameter but later directional drilling was applied and managed pressure drilling by aerated water in the reservoir part. The majority of the wells were, however, drilled of the Large Diameter type. They were directionally drilled with Measurement While Drilling tools (MWD) and a mud motor. Data was analysed from a total of 50 wells, having different well designs (A or B), trajectories (vertical vs. directional) and drilling fluid (water only vs. aerated water) which allows comparisons of performance by statistical analysis.

The objective of the MS study was to analyse the data to gauge the risk and identify where improvements might be made. The data for time, depth and activity were derived from the Geologist Daily Reports, as the Rigs Daily Reports with the KPI were not made available. The resolution of the time data and its breakdown is thus not as high as it could have been.

2.2 Well output study

The second part of the study analysed the well output and indications thereof during drilling. Measurements with the drilling rig still on the well are by recording fluid losses and determining how the well accepts fluid at the end of drilling. From Step Rate Injection Tests one can determine the Injectivity Index II, (kg/s per bar) and other reservoir parameters. This has been considered a good indicator of success as far as the eventual output of the well is concerned. After the rig is moved off and the well has heated up the real output can be measured by flow-testing. Then the Mass Flow (kg/s) vs. Wellhead Pressure (bar) is measured for several points, together with the Enthalpy (kJ/kg). By Step Rate Flow testing the “reverse” of the earlier injection test can be performed to obtain the productivity index (PI, kg/s per bar). Although these tests “mirror” one another the PI is often half of the II due to thermal dilation of the fractures.

The inclusion of the output data in the analysis allows an overall comparison of the success. The question of which technology produces the best results is one of the objectives of such a study .Which type of well design to select, vertical or directional, managed pressure drilling or straight water and even the selection of drilling rig. Then again we may have less control than we imagine, as the main determining factors affecting success have to do with the geothermal reservoir. There the permeability structure and temperature are key to the output. Such reservoir data is primarily obtained by drilling. By integrating all the data collected from the rig and through logging and testing, new knowledge is gained that aids the decision-making process and ultimately in improved results.

2.3 Results

It is beyond the scope of this paper to describe the details. Below some examples from the work are presented together with some of the conclusions.

1. The time to drill a Large Diameter well (44.1 days) takes just slightly less time to drill than for a Regular Diameter well (46.9 days). As the surface casing is pre-drilled with a smaller trig the actual days of the large rig is only 38 days for the Large Diameter wells and 39.3 days for the Regular Diameter well. It is rather surprising that the larger wells are quicker to drill. Similar drilling rates are maintained for both designs (~10 m/hr) and there is slightly less tendency to get stuck in the large hole. One additional explanation is that the Large Diameter holes were drilled later in the drilling campaign when more experience had been gained. This result is not unexpected as in other fields, where both designs have been used, almost identical number of days is required to complete a well.

TABLE 1: Estimated time to drill a “reference well” of two designs to 2175 m, based on actual rig performance (data from Sveinbjörnsson, 2010)

	Surface csg.		Anchor csg.		Production csg.		Open hole (liner)		Total	
Casing progr.	**Days**	**SD (σ) %**	**Days**	**SD (σ) %**	**Days**	**SD (σ) %**	**Days**	**SD (σ) %**	**Days**	**SD (σ) %**
Regular Diameter	6,3	2,6	8,7	3,8	10,6	4,2	21,3	7,6	**46,9**	9,8
Large Diameter	6,1	2,2	8,4	2,3	10,5	2,8	19,1	6,6	**44,1**	7,8

2. Out of all the wells, 19% had problems during drilling. Where there were more than 3 standard deviations (3 sigma) from the average time of any one section, it qualified being listed as a problem well.
3. Three rigs of rather similar design were engaged, having hook load ratings of 100 tonnes, 200 t and 300 t. The drilling rig with the highest hook load (300 t) got stuck or had to fish more often and for longer periods, than the two smaller ones. Inverse of what one might think- perhaps control of a large rig makes the drillers too heavy-handed! The smallest rig 100 t was though only drilling to 1100 m.
4. The average output of wells MWe was the same for Regular Diameter wells 5.7 MWe and Large Diameter ones 5.8 MWe (Table 2). This indicates that the output is more controlled by the inflow performance from the reservoir to the wellbore, than its casing diameter. The larger flow expected from bigger diameter wells is not realized, unless the permeability is exceptionally good. The output varies a quite lot from well to well and there are nine wells in the sample of with more than 13MWe in output.

5. The correlation between the Injectivity Index (II) and measured output determined by flow testing was not very good. The reason is partly due to different temperatures over the field and the way the measurements were carried out was not consistent. As an example of the correlation the following figure is for wells where the enthalpy was below 1400 kJ/kg (not two-phase in the reservoir).

TABLE 2: Average output of Regular Diameter wells and Large Diameter wells (Sveinbjörnsson, 2010)

Casing Program	Number of wells (#)	Average Output (MWe)
Regular Diameter (9 5/8")	15	5,7
Large Diameter (13 3/8")	38	5,8
TOTAL	53	5,8

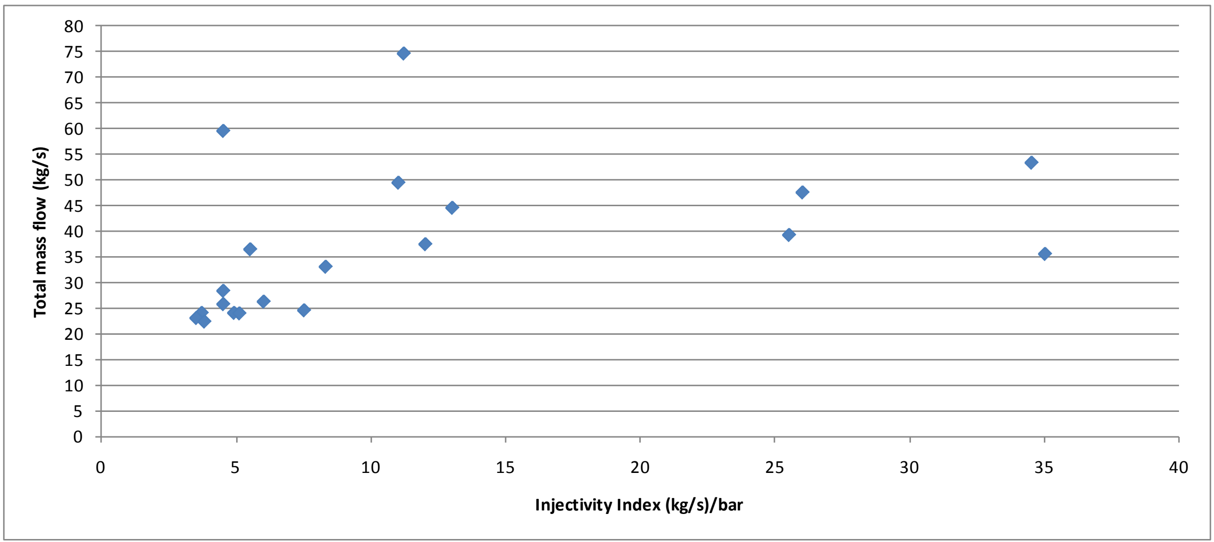

FIGURE 1: Correlation of Injectivity Index at the end of drilling to actual mass flow measured during in flow testing. The data is from wells having an enthalpy under 1400 kJ/kg. (Sveinbjörnsson, 2010)

6. There was no clear "winner" in terms of well output that can be related to the well design or which drilling method was employed. Thus the large diameter wells, directional wells or wells drilled with aerated water, or wells that received thermal cracking stimulation, did not outperform the alternatives which are less expensive to drill. The above conclusion is derived from grouping the wells into categories out of a total of 73 wells. There are more wells in the output sample (73) than for time data (50), as the additional data became available from new wells after completion of the time study. This goes against widely held opinions in the geothermal industry on the benefits of directional drilling and managed pressure drilling. Because of the large difference in well outputs the counter argument can probably be made, with data

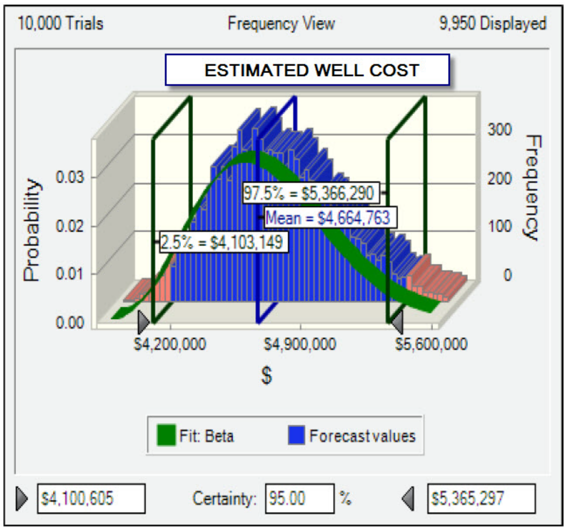

FIGURE 2: Distribution of expected drilling cost for a 2175 m well (Sveinbjörnsson, 2010)

from other areas or sample sizes. Added note: In all five high-temperature geothermal fields being exploited in Iceland, the highest output wells are drilled vertical and without aerated water (w/o managed pressure drilling).

7. A cost estimate was prepared for a "reference well" of Large Diameter directionally drilled with managed pressure to 2175 m measured depth. A Monte Carlo calculation was made to reflect the uncertainty, using the statistical drilling data for the time estimates and prevailing unit costs for rig and material. Price ranges were assigned to the unit costs and coupling the two produced the following results:

3. TIME STUDY OF WELLS DRILLED IN KENYA AND ICELAND

3.1 The wells

This study by Thomas Miyora Ongau, a UNU Fellow in 2010, compared the time required to drill12 directional wells from Kenya to 14 similar wells from Iceland. These selected wells have Regular Diameter casing sizes but the Kenyan wells are deeper (Table 3). The wells have 9 5/8" production casing and are directionally drilled to total depth with a 8 ½" bit. The Iceland wells are a subset of the wells analysed in chapter 2 and the time data for the Kenya wells is from drilling records and recorded KPI's.

TABLE 3: Depths of wells in Kenya and from Iceland, Regular Diameter (Ongau, 2010)

Kenyan wells		Icelandic wells	
Steps	**Depths (m)**	**Steps**	**Depths (m)**
0	0-60	Pre-drilling	0-90
1	60-300	1	90-300
2	300-1000	2	300-800
3	1000-2800	3	800-2300

TABLE 4: Break-down of drilling time in percentages for similar wells in Kenya and Iceland. (Ongau, 2010)

	Drilling	Casing	Cem.	Plug	Stuck	Ream.	Fish	WOW	bit/BHA	Repair	Cleaning	Meas.	Other
Kenya	57.94	4.42	7.40	0.47	1.26	3.22	0.42	0.37	9.55	2.02	1.66	4.93	6.35
Iceland	45.31	8.33	5.29	4.45	4.99	2.16	0	0.12	0.95	1.16	9.43	17.52	0.28

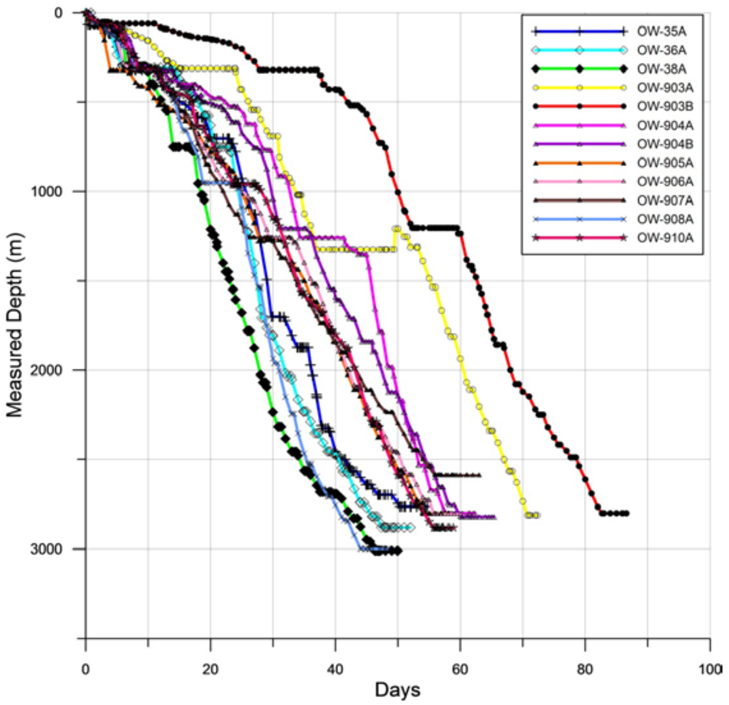

FIGURE 3: Drilling progress curves from Kenya, depth vs. working days (Ongau, 2010)

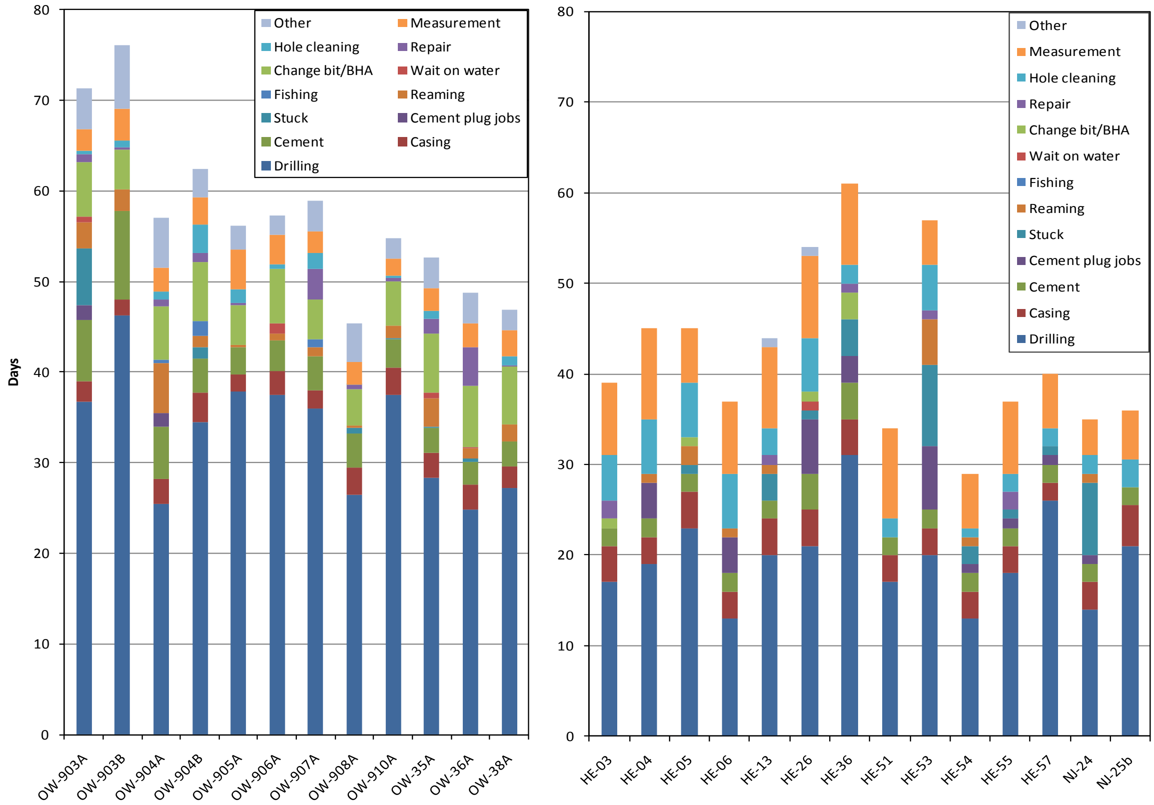

FIGURE 4: Time analysis for Kenyan wells and Icelandic wells (Ongau, 2010)

3.2 Results

1. Rate of penetration. The results show that the average advance for Iceland is about 56 m per day and for Kenya about 48 m per day.

2. The average depth of the Icelandic wells is 2379 m taking 41 days to drill whereas the average depth for the Kenyan wells is 2830 m in 58 days.

3. Based on the historic data for the same depth of well, the difference is 4 days, not very great. In comparing the length of each activity (Table 4) the following was found:

   a. Kenya uses ten times more time to change bits due to shorter bit life and changing the angle correction bottom hole assemblies (BHA) as mud motors are not used to total depth.
   b. Four times more time is spent on well logging in Iceland due to a full geophysical suite (lithological) at each casing depth, more frequent temperature logging, caliper logging and cement bond logs, and for gyroscopic surveys to confirm the trajectory. The logging in Kenya is limited to temperature and pressure and single-shot directional surveys for steering.
   c. There were other minor differences identified such as more time spent in Iceland on circulation to clean the hole or stimulate it and also on fishing.

4. CONCLUSIONS

A wealth of information is collected at the time of drilling a geothermal well. The analysis of key performance indicators between wells and also for different technologies applied can produce valuable insight into the level of risk and how improvements can be made. This will moreover lead to more accurate estimates and be an aid in the decision making process. Coupling this with analysis of the well output, valuable lessons can be learned on ways to improve the success and, which technology to apply, once enough data has become available. It is considered important to apply such analysis early in the drilling effort of a new field to shorten the "learning curve". For the moment detailed analysis is only possible internally for each company as the rig data and results from well testing and draw-down with time is generally confidential information. Information on the surface exploration, lithology, fluid chemistry even reservoir simulation studies and the overall power development is, however, not as tightly guarded and is found widely in the geothermal literature and presented at conferences. The two case histories presented here are intended to illustrate what can be learned. Results from other fields are likely to differ, but early identification of the peculiarity of each resource and the identification of the appropriate technology are keys to success. If such time/cost and well output data were more widely available for analysis it could be used to identify good drilling practices and assess the benefits obtained by stimulation. Because of the overriding influence of well output on the project economics, methods to improve the prediction of final output with the rig still on the well is receiving special attention. For wells judged to be poor the option is to drill deeper, sidetrack or go to well stimulation. Work is ongoing as how to apply this knowledge to the decision making process and ultimately to reduce the cost of tapping the geothermal resource for power generation.

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