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LESSONS LEARNED IN DRILLING DB-1 AND DB-2 BLUE MOUNTAIN, NEVADA

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ABSTRACT

The second stratigraphic test well, DB-2, drilled at the Blue Mountain Geothermal Project 30 kilometers (20 miles) west of Winnemucca, Nevada, was successfully completed on April 29, 2004. The hole was drilled under a cost sharing agreement between Noramex Corp. and the US DOE under the GRED II program to explore the geothermal resource to the west of Blue Mountain in an area previously explored for gold.

Noramex drilled DB-1, the first deep stratigraphic test well, to 672.1 meters (2205 feet) in 2002. DB-1 intersected economic temperatures of 145°C (292.5°F) at a depth of 645 m (2115 ft). DB-1 had lost circulation and indications from the temperature survey of high permeability in the almost 366 m (1200 ft) of hole with high temperatures.

DB-2 encountered higher temperatures, 167°C (333°F) at 585.2 m (1920 ft), also with good indication of permeability from lost circulation and from the temperature surveys from 201.17 m (660 ft) to bottom.

Both wells were drilled with close cooperation and assistance from Sandia National Laboratories. The first well tested the resource along a major north-south trending fault. DB-1 was planned with 7" casing cemented to a depth of 120 m (400 ft) and 4 ½" casing cemented to a nominal depth of 250 m (820 ft). The hole was drilled using a Universal Drill Rig 1500, capable of drilling both the rotary and core sections. The upper part of the hole in the cased intervals was planned for rotary drilling and cementing by the displacement method.

Massive zones of lost drilling circulation required constant remedial work and attention in the upper part of DB-1. The loss zones caused difficulty in cementing both the 7" and the 4 ½" casing strings. Shallow, hot fluid was later found to be migrating down behind the 4 ½" casing from a zone near the bottom of the 7" casing indicating that a complete cement bond was not achieved. Drilling of DB-1 took 43 days from spud to completion.

The second well, DB-2, tested faults to the north of DB-1 in a second area of high temperature anomaly closer to the range front. DB-2 was planned to use flooded reverse circulation technique for the single string of 4 ½" casing to be cemented to 200 m. (650 ft.) using the tremmie pipe method. This method would allow the hole to advance despite lost circulation. Although cementing with tremmie pipe requires an oversize hole, it allows cementing to surface despite the presence of severe loss zone. Below the cemented casing, the hole was to be HQ cored to total depth of 1000 m (3281 ft) using a different rig set up for wireline coring. Noramex relied on information gained from Sandia's research into the use of these techniques to combat the problems of lost circulation, to help make the decision to change the drilling strategy for DB-2.

This plan was very successful and smooth progress allowed DB-2 to be drilled to a depth of 1128 m (3700 ft) or 11% deeper than originally planned in a total of 33 days from spud to completion. Circulation problems in the open hole below the cemented casing, but above the temperature target for the well were controlled using lost circulation materials. A cement plug was finally set after coring through this zone to reduce the potential for down-flow of cool water.

INTRODUCTION

The geothermal resource at Blue Mountain Nevada was first discovered during drilling for precious metals on mineral claims in the early 1980's. Hot water with temperatures up to 190°F was encountered in holes drilled for gold exploration. Noramex acquired the geothermal rights to two sections of private land and five sections of BLM land in 1993 and 1994. Noramex then remapped the area, examined aerial photos, ran an SP survey and drilled 11 new coreholes as part of a geothermal exploration and evaluation effort.

Structural mapping identified three primary fault sets related to Basin and Range tectonics: The oldest faults trend nearly northwest and are steeply dipping. Next in age, north-south trending faults such as the, Central, West and Graben Faults, dip west and offset earlier gold mineralization. (Map 1) The youngest faults trend to the northeast and dip steeply west, also offsetting the gold mineralized zone. An SP survey conducted as part of the exploration program indicated a zone of geothermal fluid upwelling.

DRILLING OF DB-1

In 2000, Noramex proposed a 2300 ft (700 m) deep hole to test the geothermal potential at Blue Mountain and secured a cost-sharing agreement with the US Department of Energy under the GRED program, DOE contract No. DE-FC04-00AL66972. The contract was administered through Sandia National Laboratory and technical assistance was provided by Sandia as well.

In April of 2002, Noramex began drilling of DB-1. The well was sited to intersect the north-south trending West and Central faults in a thermal anomaly found with shallow gradient holes. DB-1 was planned with 7" casing cemented to a depth of 120 m (400 ft) and 4 ½" casing cemented to a nominal depth of 250 m (820 ft). The hole was drilled using a Universal Drill Rig 1500, capable of drilling both the rotary and core sections. The upper part of the hole in the cased intervals was planned for rotary drilling and cementing by the displacement method.

A hung liner of used drill rod with a diameter of about 2 3/8" was planned to keep the hole open for testing and logging.

A permeable zone at 49 m. (163 ft) produced artesian hot water. Circulation was first lost at a depth of 84 m. (276 ft.) in highly altered, fractured rock. The loss was controlled with cottonseed hulls and sodium bentonite granular plugging material and a cement plug. At 99 m (325 ft), circulation was again lost, but could not be controlled. After setting 6 cement plugs and pumping significant amounts of loss control material, the hole had only advanced to 105 m (345 ft.) by drilling with no returns. In order to be able to drill ahead, the 7" casing was set, but hung up in the fractured zone and was finally set at 98 m. (321 ft.) in highly altered fractured rock, probably the West Fault.

Attempts to drill ahead with rotary drilling were unsuccessful due to continued loss of circulation. Finally, the hole was advanced by switching to coring with PQ size tools at 112 m. (367 ft.) The hole was drilled without returns to 176 m. (579 ft.) No further attempt was made to control losses. The 4 ½" casing was set at 175 m. (573 ft.) in metasedimentary argillite with significant quartz veining and brecciation with open spaces.

The hole was completed by coring with HQ sized tools to a depth of 672 m. (2205 ft.) without regaining circulation. An unstable zone in fractured and highly altered felsic dike material was encountered at around 225 m. (737 ft.). This zone made it difficult to run the liner tubing to bottom and may have caused later problems with running temperature surveys. The well completion with loss zones marked is show in Figure 1.

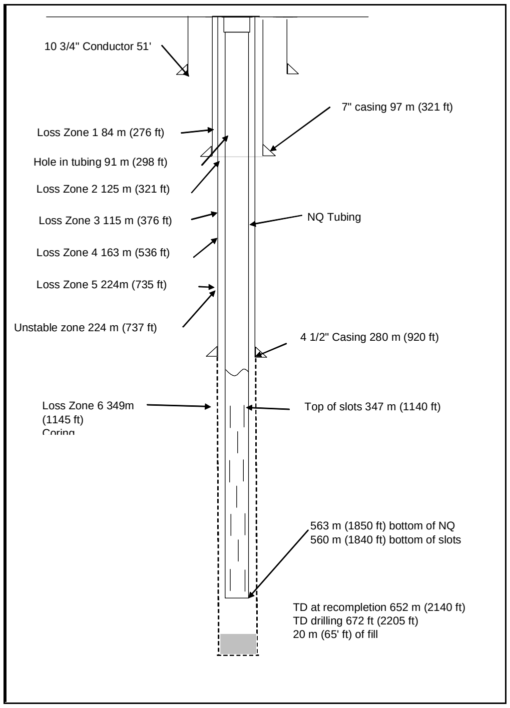

Figure 1. DB-1 permanent wellhead and well profile

Cementing of the DB-1 casing was complicated by the severe loss zone at the casing shoe for the 7" casing, and by the small annular space and lost circulation in fractured rock behind the 4 ½" casing. During logging for well testing, it was discovered that shallow, hot fluid is migrating down behind the 4 ½" casing from a zone near the bottom of the 7" casing indicating that a complete cement bond was not achieved. (Figure 2).

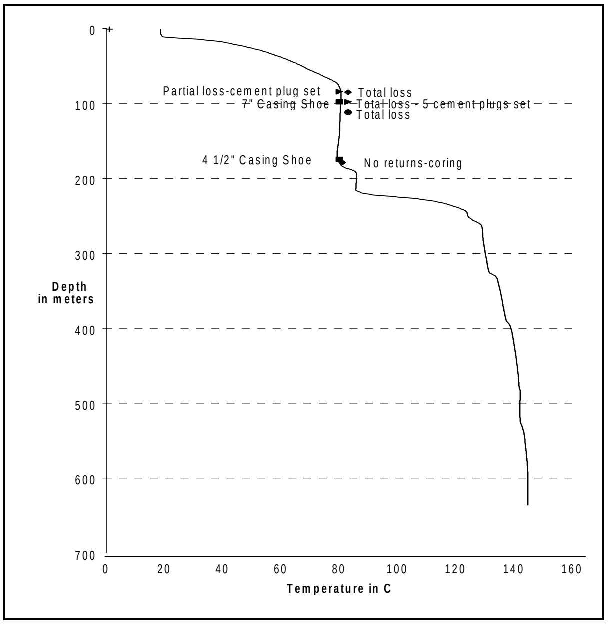

Figure 2. Temperature profile of DB-1.showing loss zones.

'The drilling cost of DB-1 exceeded the original cost estimate and the GRED grant had to be extended to complete the hole. The total drilling time was 43 days with 47 days from spud to rig release. A plot of drilled depth with time is shown in Figure 3. Note that the loss zones correspond with periods where not progress is made.

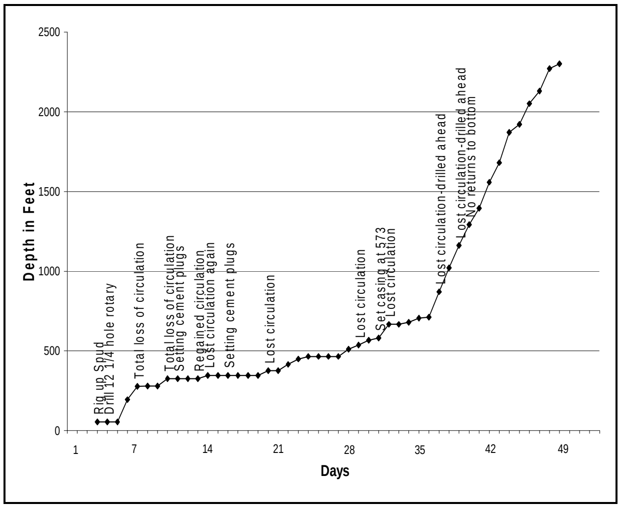

Figure 3. DB-1 drilling history.

DRILLING OF DB-2

The experience with the drilling of DB-1 lead Noramex to review the drilling program when planning for DB-2. With further cost shared funding from the DOE GRED program, the hole was planned from the start to deal with expected large-scale circulation losses. Sandia National Laboratory again provided administrative oversight and technical assistance in planning and drilling of the hole. Since one of Sandia's primary research objectives is finding methods to deal with extremes of lost circulation during drilling of geothermal holes, data and information was available to help Noramex succeed in drilling this second hole within their budget.

During cost estimating for DB-2, a drilling contractor experienced in geothermal drilling proposed the use of flooded reverse circulation drilling. This method, frequently used in water well drilling, circulates drilling fluid down through the annulus of a dual walled drill string. Cuttings with drilling fluid then return through the inner string. This reduces the loss of drilling fluid and the risk of differential sticking and high torque by maintaining fluid around the bit and bottom hole assembly. Although the drilling contractor on DB-1 had done everything feasible to control lost circulation (see Figure 7) showing a comparison of drilled depth vs. time, shows that the losses brought drilling virtually to a standstill until the switch was made to coring.

Sandia had an ongoing research program studying the use of flooded reverse circulation drilling to deal with lost circulation in geothermal drilling. (Rickard, 2001) They provided information on the method that reassured Noramex that the technique would be beneficial in controlling costs and should work well in Basin and Range drilling at Blue Mountain.

The hole was planned to use flooded reverse circulation drilling in the cased part of the hole to control losses. Coring would then be used after the casing was set.

After discussion with Sandia, the hole was planned for cementing through the annulus from the bottom up with tremmie pipe. (Rickard, 2001) This requires a larger annulus, so the intermediate 7" casing string was eliminated. A 9 5/8" hole was planned for the 4 ½ casing to accommodate the tremmie pipe cementing. Since Sandia is also studying tremmie pipe cementing and other cementing methods to deal with loss zones behind casing, they were able to provide data to support the feasibility of tremmie pipe cementing long intervals in a geothermal setting.

The hole site was also selected to intersect any faults at a deeper depth than DB-1. This would keep the loss of fluid to the smaller diameter hole and thus reduce the cost of the loss, while also making the faults potential production zones.

The 10 ¾" casing was set at 56 ft in silicified meta-sediments and the hole was drilled out with a 9 7/8" bit for the 4 ½" casing. The first loss zones in DB-2 were encountered at 85 m (280 ft) and drilling was switched to flooded reverse circulation. Circulation was eventually regained after drilling ahead with some loss additives. Two more loss zones were encountered, but could be drilled through with reverse circulation and loss control additives.

The 4 ½" casing was set and cemented in place with no trouble. Tremmie pipe was used to stage in the cement, with time between each batch for the cement to set. Cement was successfully pumped to surface despite the loss zones in the cemented interval.

The remainder of the hole was cored with HQ sized tools. A significant loss zone was encountered at 203 m (665 ft). The loss was cured with loss additives of shredded paper, and Magma Fiber, an extrusion-spun mineral fiber as well as Drispac, a long-fiber cellulose polymer. Several more loss zones to a depth of 240 m (788 ft) were cured with LCM, but the zone was finally cemented from 240 m (788 ft) to the casing shoe at 201 m (660 ft) after temperature measurements showed that it was probably below the temperature of the main reservoir. Cool water zones can down flow into hotter zones below, making it difficult to test the well and obtain unmixed reservoir fluid samples. However, this zone later heated up to reservoir temperature, and the cementing of the zone was found to have caused some formation damage. Figure 4 shows the completion of DB-2 with the loss zones marked.

Although, for the most part, coring in DB-2 allowed drilling ahead, in deeper zones once target temperatures had been reached and mud additives had been reduced, high torque became a problem. Torque reduction additives helped reduce torque, but near the bottom of the hole the pipe stuck despite torque additives. The stuck pipe was quickly fished and drilling progressed to TD without further problems.

Figure 5 shows the temperature profile of DB-2 immediately after drilling. The temperature at the loss zones below the casing shoe to a depth of about 584 m (1925 ft) are lower than the maximum temperature. The loss at 238 m (775 ft) was cemented to prevent flow of cool fluids down the wellbore where they could cool off the deeper zones and mix with hotter fluids.

Figure 6 shows drilled depth vs. drilling time for DB-2. It is clear from this plot that the only period where no progress was made was the time needed to change out the rigs to switch from reverse circulation drilling to coring.

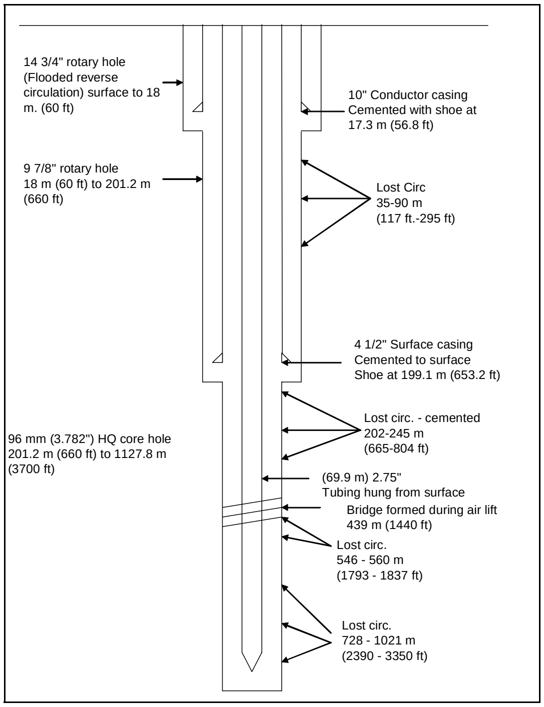

Figure 4. DB-2 well profile with loss zones

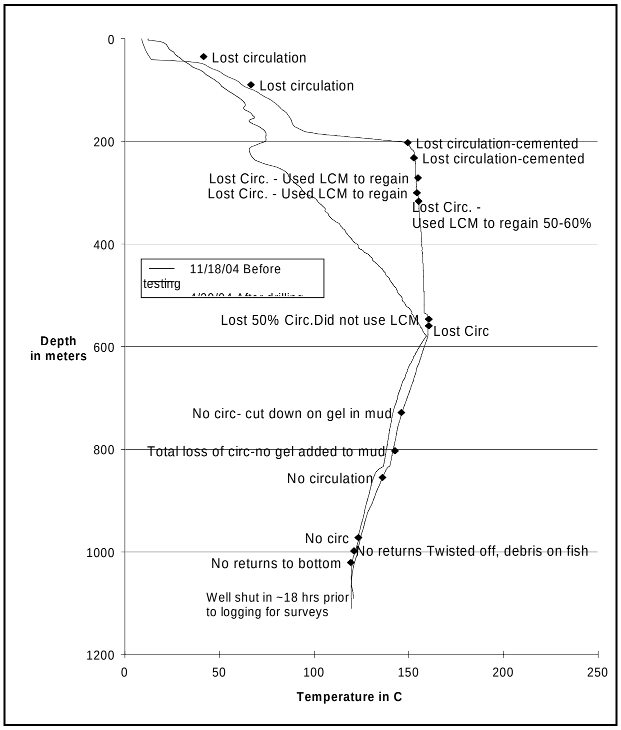

Figure 5. DB-2 temperature profile immediately after drilling.

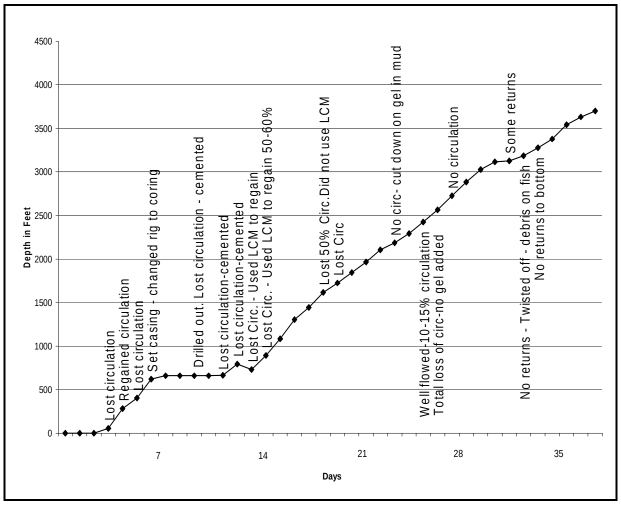

Figure 6. DB-2 drilling history.

COMPARISON OF DRILLING EXPERIENCE-DB-1 & DB-2

Several factors besides the drilling methods differed between DB-1 and DB-2:

- DB-1 was sited close to the surface expression of the steeply dipping Central Fault, in the hope of intersecting it or the West Fault at depth.
- DB-1 intersected the Central fault much shallower than anticipated, with much more problematic lost circulation than if the fault had been intersected deeper.
- Lost circulation was much more severe over a longer, shallower interval in DB-1 than in DB-2.
- Severe hydrothermal alteration in DB-1 caused hole instability. Alteration was also severe in DB-2, but it was encountered at greater depth.
- In DB-1, lost circulation was encountered first at about 84 m (276 ft) with the most severe losses ended by 115 m (376 ft). In DB-2, the first loss was encountered at a similar depth, 85 m (280 ft), but it didn't become severe until just below the 4 ½" casing shoe at 203 m (665 ft). The severe losses continued until 317 m (1040 ft) when LCM sweeps regained partial returns.

It is difficult to separate the less severe lost circulation problems in DB-2 from the improvement in drilling technology, but an overall comparison of the two holes can be made and then allowance for the different drilling conditions can perhaps be overlain afterward.

Figure 7 shows a comparison of drilled depth with days of operation for both wells. The slow progress in the severe loss zone in DB-1 from day 8 at 84 m (276 ft) to day 32 at 176 ft (579 ft) after the casing was set and the cement drilled out is clear from the graph. Even after switching to coring on day 20 at 105 m (345 ft), progress is still slow through these loss zones. Core from this area shows that the drilled rock was broken and altered with open fractures. By comparison, DB-2 does not have similarly highly fractured and broken rock until about 216 m (710 ft). However, DB-2 was not cored in the interval where the large losses occurred in DB-1.

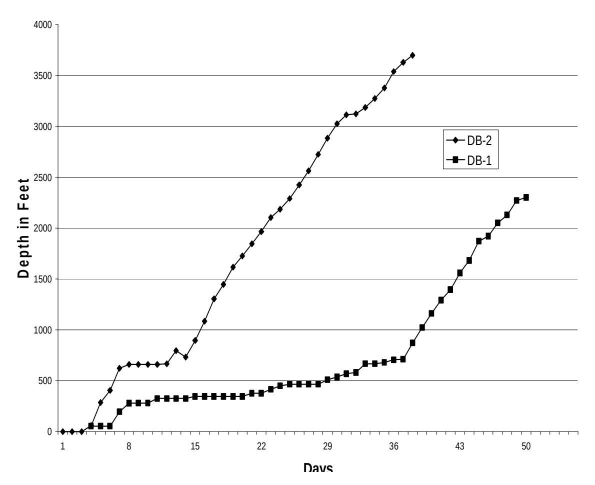

Figure 7. Comparison of DB-1 and DB-2 drilling days with depth.

In order to better understand the difference between the two wells, rate of penetration, ROP, was compared (Figure 8). ROP was calculated by dividing the total footage drilled during each shift by the hours that the bit was rotated. This eliminates time spent pumping LCM sweeps and tripping. It is obvious from this plot that DB-2, with the use of flooded reverse circulation, had much higher ROP through the shallow interval than did DB-1. ROP after both wells were cored is similar.

Drilling fluids used in the two wells were similar. Both were bentonite based. However, lost circulation material chosen for DB-2 included the use of long fiber cellulose polymer Drispac along with the cotton seed hulls used in DB-1. For particularly difficult sections, a spun mineral fiber was added in DB-2 along with a diatomaceous earth based loss control material. It isn't clear how much difference this made, but it is possible that these additives helped recover circulation during coring.

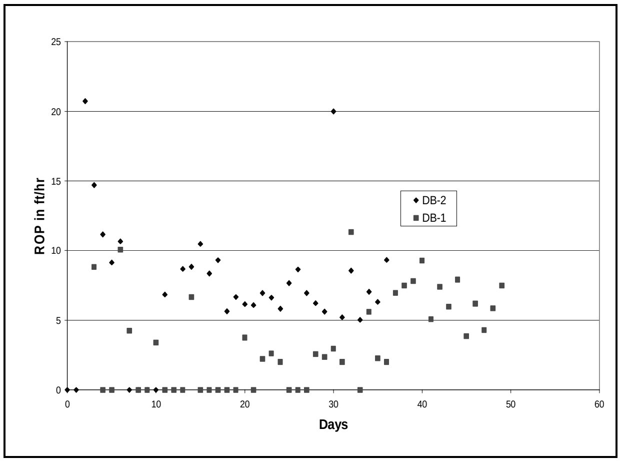

Figure 8. DB-1 and DB-2 rates of penetration

The dual tube reverse circulation allows drilling to continue even when losses occur as long as the bit and drilling assembly have fluid around them. The method not only saves the time spent attempting to recover circulation, it also reduces torque and the risk of twisting off, and can extend bit life and reduce the amount of tripping, thus saving rig time and improving drilling economics. Figure 9 shows a comparison of bit life for DB-1 and DB-2. Bit life for DB-2 is significantly higher throughout the depth of both wells, even through the cored sections. Based on core photos, rocks in both wells appear to have similar drilling characteristics. In some sections they are highly silicified, which could make rocks harder, decreasing bit life.

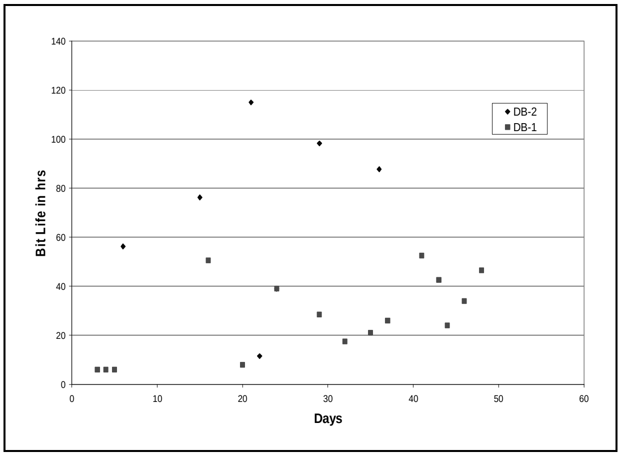

Figure 9. DB-1 and DB-2 bit life comparison.

The highly fractured sections can also decrease bit life due to uneven loading. However, the softer altered zones found in DB-1 should have improved bit life. The most likely conclusion to be drawn from this data is that the bits used in DB-2 wore better in these rocks than those used in DB-1. This emphasizes the importance of proper bit selection in keeping hole cost under control.

Another factor in extending bit life is reducing wear on the gauge cutting surfaces on the sides of the bit. High torque and uneven loading caused by highly fractured and hard rocks can decrease bit life rapidly. Drilling fluids used in DB-1 and DB-2 included additives to reduce torque and lubricate the bit through sections with fluid loss when the bit might not have had as much fluid cooling it and torque might have increased wear. It is clear from noted torque measurements in the drilling records that these additives worked to reduce the torque when it built up except in DB-2 where pipe stuck near the bottom of the hole..

Another factor in improving the outcome of DB-2 compared to DB-1 was the use of tremmie pipe cementing in stages. This allowed a good cement sheath in sections where losses had occurred and not been cured. Cementing with tremmie pipe took slightly longer than conventional cementing by displacement through the bottom of the annulus used in DB-1. With tremmie pipe, an extra half day was needed for setting the small diameter pipe before running the casing. However, this would be worth the extra time to ensure a good cement job, particularly in a highly fractured zone with corrosive fluids such as wet CO2 or H2S rich steam. It is clear from the temperature profile in DB-1 that fluid is flowing down behind the casing in DB-1 due to a poor cement job in the area with severe fluid losses.

One of the recommendations from Sandia for improving loss control with cement is the pumping of sodium silicate into the loss zone ahead of the cement. This causes the cement to harden at the leading edge as it is injected into the formation, slowing the advancing cement front. This was suggested to help cure the loss zone in the section just below the 4 ½" casing shoe in DB-2, but from the drilling record it does not seem to have been tried, although commercial additive names don't always reveal the content of the additives. It might have been helpful in DB-1 when multiple cement plugs were set to try to control losses around 98 m (320 ft).

LESSONS LEARNED

Despite the differences in drilling conditions, some important lessons can be gleaned from the shortened time and cost for drilling DB-2 compared to DB-1:

- Open fractures, particularly at shallow depths can result in extreme losses of circulation. If it is at all possible, wells in areas of steeply dipping faults should be sited down dip from the surface expression of the fault to avoid intersecting these open fractures at shallow depths.

- Use of flooded reverse circulation can reduce drilling time and improve overall ROP in areas with lost circulation. Bit life in loss zones can also be improved using this drilling method.

- Although coring can allow holes to be drilled despite circulation loss, with extreme losses and highly fractured rock, coring is not a panacea since high torque and stuck pipe can still occur.

- Selection of LCM is important. If cement is used for loss control, additives or use of improved techniques may improve success.

- If loss zones can not be sealed or, due to the drilling method chosen, are not attempted to be sealed, use of an alternative cementing method, such as tremmie pipe or reverse circulation cementing down the annulus may allow for a good cement job.

- When coring ahead without returns, use of lubricant mud additives can improve bit life and ROP, and thus overall drilling performance.

These wells are typical of drilling conditions to be expected in the Basin and Range and so should allow us to apply the lessons to planning future drilling. The next step is to apply these methods to larger, production diameter wells.

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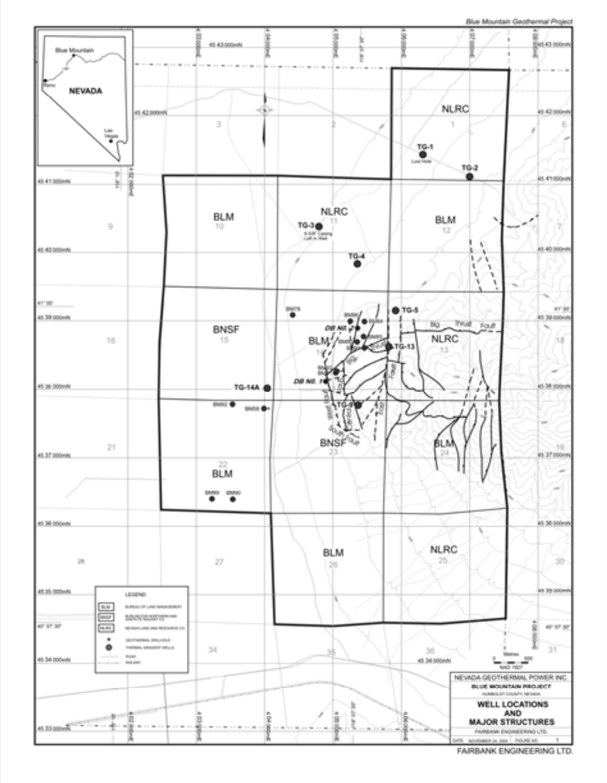

Map 1. Structure and well locations at Blue Mountain, Nevada.