Deep Core Drilling of Three Slim Geothermal Holes, Snake River Plains, Idaho

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ABSTRACT

A deep core drilling project focused on evaluating the geothermal potential of the Snake River Plains in southern Idaho. Slim-hole continuous diamond coring and associated geophysical surveys were used to sample different geothermal environments. Three locations were drilled with target depths as follows: Kimama 1915 m, Kimberly 1959 m, and Mountain Home 1821 m. All total depths were accomplished or exceeded. A continuous core sample was produced and down-hole temperature while drilling was collected.

Introduction

Geothermal environments pose unique challenges for exploration reservoir assessment and production drilling. For exploration and assessment purposes, coring presents the advantage of observing reservoir lithologies, hydrothermal mineralogy and fluid inclusions, fracture character as well as offering the opportunity to measure down-hole temperature (Hulen and Nielson, 1995; Nielson *et al.*, 1996; Nielson *et al.,* 1998). Reservoir engineering data can be acquired from slim-holes (Garg and Coombs, 1997). The cost of core drilling is known to be lower than production well drilling, and coring can be done to the depths of production wells (Nielson, 2001). These factors have led many companies to conduct core drilling prior to bring in the more expensive production rigs. However, there are few papers that document operating experience and costs as well as the scientific benefits of coring.

The Hotspot Project was designed to evaluate three different geothermal environments in the Snake River Plain (SRP) (Shervais *et al.* 2012). The effect of fresh water aquifers on high heat flow from this large magmatic province is well established (Blackwell, 2011). Because of this, deep coring was necessary.

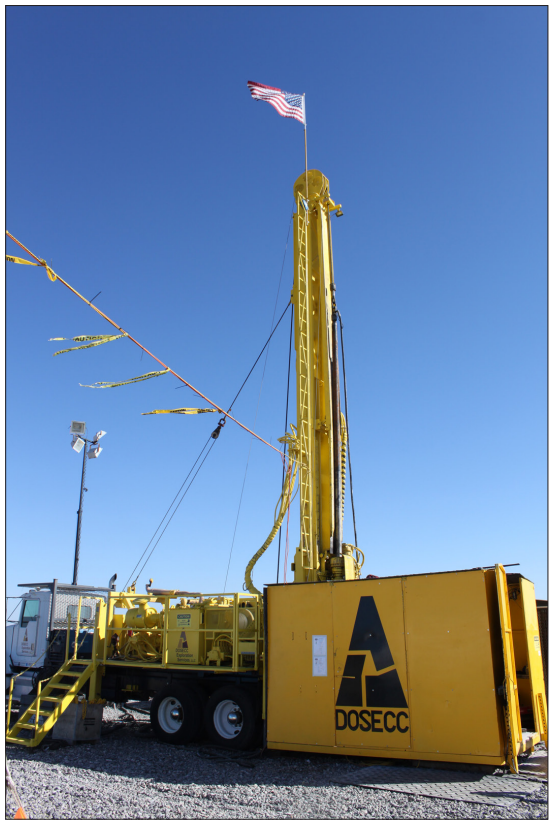

Figure 1. DOSECC CS-4002 core drill rig.

The coring took place from September of 2010 through October of 2011. The sites were chosen to evaluate three different geothermal environments: the axis of the eastern SRP, the southern margin of the SRP and an axial area on the western SRP. These holes were located at Kimama, Kimberly, and Mountain Home Air Force Base. All core drilling, was performed by DOSECC Inc. (Drilling Observation and Sampling of the Earth's Continental Crust) of Salt Lake City, Utah, and under Idaho well drillers license 656. Additional air rotary services were performed by Eaton Drilling and Pump Services of Wendell, Idaho, and under Idaho well drillers license 026. An Atlas Copco CS-4002 coring rig was the primary drilling platform used throughout the project shown in Figure1.

All work done by Eaton Drilling and Pump Service was accomplished with an Ingersoll-Rand T3W air rotary drill rig using down hole hammers shown in Figure 2.

Figure 2. Eaton's T3W air rotary drill rig.

Kimama (42°50′21.56″N 113°47′47.66″W)

The Kimama site is located approximately 20 miles North of Burley, Idaho in the abandoned township of Kimama. There is access to the site on semi improve dirt roads, and it is seasonally dry and dusty in a loess covered basaltic field shown in Figure 3. A water well was drilled by Eaton Drilling and Pump Service to a depth of 304 fbs to supply water for the drilling phase. Site preparation at Kimama was done by consisted of clearing brush, installing a 3.5' x 3.5' x 3.5' concrete box as a mini cellar in order to fit the choke and kill ports under the well head, and still allow the annular preventer to fit under the foot clamp of the CS-4002 drill rig.

Next a woven geo-fabric was installed over a 100' x 100' area bounding the dirt access road. Engineered soils and aggregates were dispersed over the geo-fabric to provide a stable drilling pad.

Kimama Drilling/Casing Plan

The drilling and casing plan for the Kimama hole was driven by the requirements of the Idaho Department of Water Recourses (IDWR) under Idaho Code 42-238. The approved drill program was as follows and shown in Figure 5:

Drill a 10-5/8" hole to 38 feet below surface (fbs), Install a 7-5/8" casing cemented with a neat cement pressure grouted bottom up. Then drill a continuous 3.830" diameter HQ-Core from 38 fbs to 1000 fbs. Log the upper 1000 feet. A 6-1/2" rotary hole opener bit would be attached to the string and hole would be opened to 1000 feet. Install 1000 feet of 4-1/2" 0.25" wall HWT threaded casing cemented with a neat cement pressure grouted bottom up. Continuous 3.830" diameter HQ Core to 5000 fbs set

Figure 3. Drill site in Kimama Idaho, with water well installed.

Figure 4. Kimama site preparation.

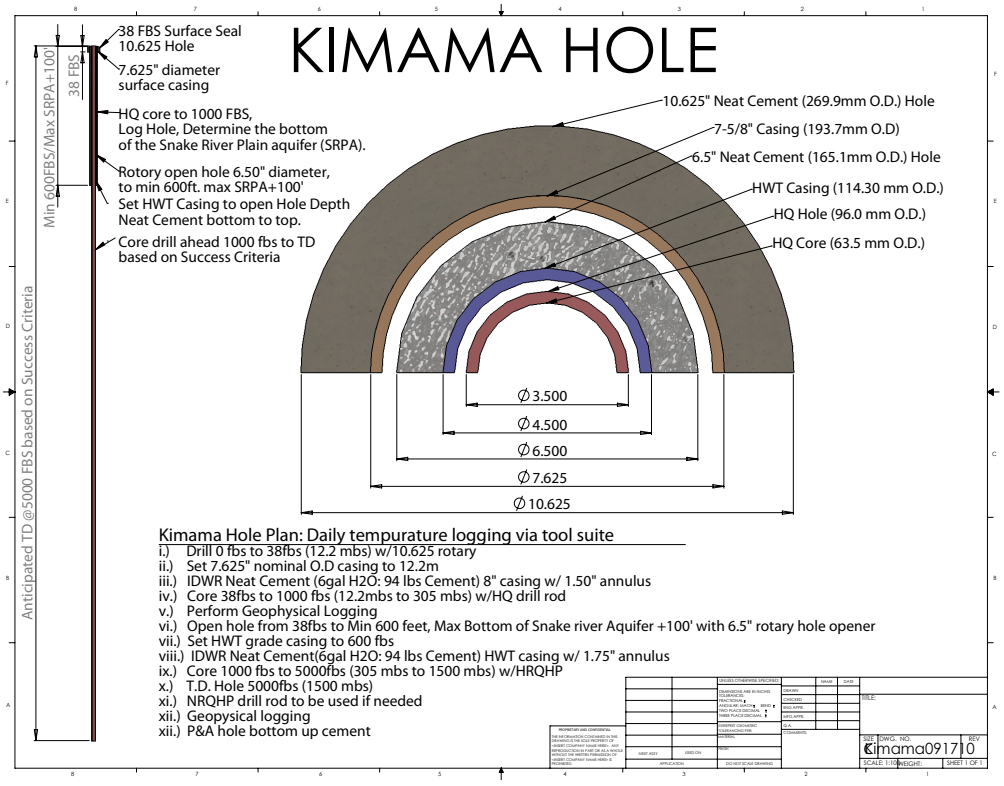

Figure 5. Kimama Hole Plan to 5000 feet.

temporary casing and drill 3.032" diameter NQ Core if needed. Run geophysical logging in the lower 4000 feet of the hole. Install 5000 feet of 2-3/8" tubing to TD and allow the well to equilibrate. Periodic monitoring of the temperature, and ultimately plug and abandon the hole with neat cement slurry installed by a tremie pipe.

Kimama Drilling History

Kimama hole is IDWR well tag D0057001 on permit number 859751, permitted to Utah State University Department of Geology. It was determined by IDWR that the use of blow out prevention devices would not be necessary until bottom hole temperatures exceeded 100ºC. We preformed temperature logging every 100 fbs and kept logs to show how the temperature increased with depth (Nielson *et al.* 2012). The Kimama hole was spudded on September 26, 2010. The entire hole was drilled without returns because permeability through the basalt section was too high for lost circulation material or cement plugs to work. Despite lost circulation, drilling went smoothly through multiple basalt, clay, and sand zones, through the top of the water table at 260 fbs until 688 fbs where the hole collapsed in a sand zone that caught the string. The rods were worked for a day and the decision was made to reduce to drill NQ. NQ core was terminated at 1097 fbs mark and tripped out. Recovery of 647 feet of the HQ rods was successful by cutting the string. The HQ rods were again tripped in to attempt drilling out the remaining steel. The hole was found to have collapsed at 647 fbs and in the clay and sand zones the drill string moved off the original hole, creating 1-B. Drilling progressed HQ to 996 fbs and the progress of the hole relative to budgeted time is shown in Figure 6.

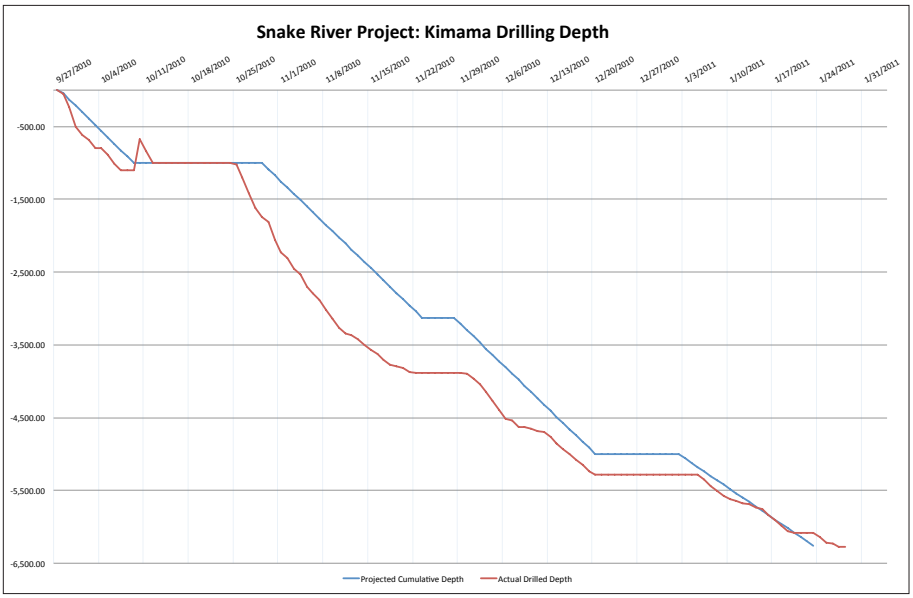

Figure 6. Kimama depth vs. time.

The following day a 6-1/2" hole opener was installed and the opening procedure started. This procedure progressed slower than anticipated, and we were concerned that at 647 fbs we would run into the HQ rod left in the hole. Hole opening progressed to 895 fbs, on October 23, 2010, where the decision was made that, the casing would be sufficiently far enough below the 10 percent hole depth to casing ratio as required by IDWR that we could cement 4-1/2" in place. Pressure grouting of the 4-1/2" casing occurred on October 23, 2010. HQ drilling proceeded to the depth of 3887 fbs and on November 23, 2010 we decided to reduce to NQ diameter to increase penetration rate. At this point the project was winterized and shut down for Thanksgiving. Drill crews reassembled on November 29, 2010, after a very harsh turn in weather shown Figure 7.

Figure 7. Kimama in winter.

Drilling resumed on November 30, 2010 reached a depth of 5000 fbs on December 16, 2010. Drilling to the original planned T.D. was accomplished on time and on budget. However, the basalt-rhyolite interface, which was an objective of the project, had not been intercepted. Drill crews assembled on January 03, 2011 and drilling resumed to 6000 fbs on January 19, 2011. The rhyolite interface had still not been intercepted and after reviewing the budget we were able to press on. Drilling ceased on the Kimama hole on January 27, 2011 at a total depth of 6275 fbs without intersecting the rhyolite.

In order to keep the hole open for future temperature measurement, a 2-3/8" casing was installed in the hole to T.D. There were two issues with the casing. It was supposed to be hung, but was landed instead and believed to have created a kink in the casing at the 4622 fbs mark. There was also a manufacturing issue that showed up when threading the casing. There was a visible non-concentricity in the pin and box ends making the I.D. smaller. The tight I.D. of 1.994" minus the non-concentricity wouldn't allow tools to pass that point in further temperature equilibrium data gathering. The geophysical logging of the hole commenced on June 29, 2011 and lasted until July, 06, 2011. The casing was used as a tremie pipe while being removed on October 11, 2011. Kimama was plugged and abandoned on October 12, 2011.

Kimama Results

Total Depth	1-A 38-1097: 1059 feet 1-B 662-6275: 5613 feet
Total footage Drilled	6672 feet
Total core recovered	6663 feet
Core Recovery	6663/6672 = .9986
Mud consumption	$ 33.80 USD/ft. (Lost circulation at the onset of hole.)
Bit usage	$ 4.88 USD/ft
Total Days	135.5 (Site Prep to demobilization, off site inclusive)
Days Offsite	22 (Holidays)
Days of Operation	103.5
Days Drilling	59.5
Days Ops not Drilling	44
Days Standby	10
ROP when coring	105.4 ft/day
ROP While Operating	60.6ft /day
ROP days invoiced	55.3 ft/day
Max Bottom Hole Temp While Drilling	61.6ºC

Results in terms of time breakdown are shown in Figure 8.

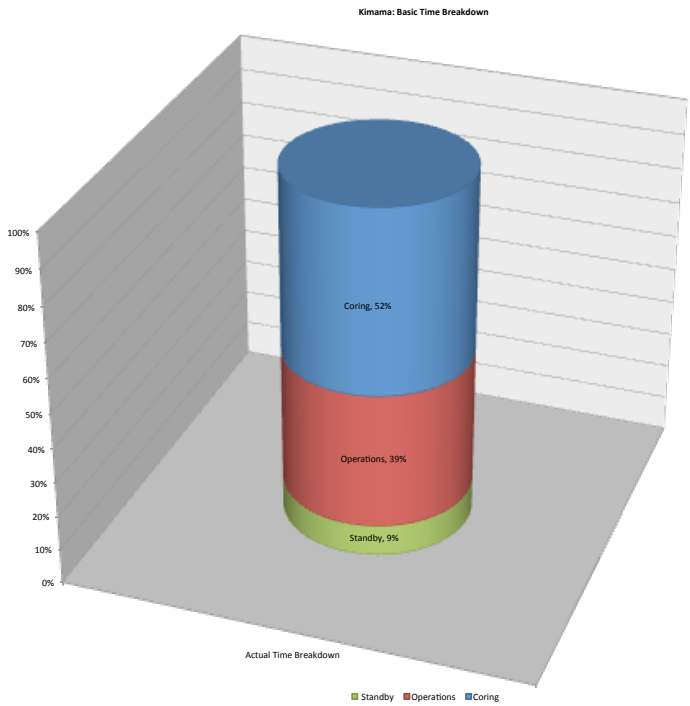

Figure 8. Kimama time Breakdown.

Kimama Lessons Learned

In the course of drilling at the Kimama location a few lessons were learned. Firstly the CS-4002 although a great drill rig for coring, is not as effective at rotary drilling with large diameter bits. A larger mud pump must be used in order to lift the cuttings at a suitable up hole velocity so that the bit does not re-work the cuttings continuously. This will help with the bit life and rate of penetration. On the subsequent holes we decided to use a rotary company to drill and set the initial 4-1/2" casing to 10 percent of the hole depth or greater. Secondly, the decision to change casing vendors was made due to the over and under alignment of the threading. It is believed that this was a large factor in not being able to pass the 4200 foot mark in the tubing. In general the casing did its job but the machining was crude. Lastly, we needed something better for loss of fluids. The upper 280 feet of the Kimama area before hitting the water table was so porous and permeable that we could not get cement to plug the lost circulation. Cement was pressure grouted on the back side of the 4-1/2" casing to ensure as good of a job as possible, but what should have been a four cubic yard cement job ended up consuming 50 cubic yards of cemented material in order to close off the casing annulus.

Kimberly (42°32′59.39″N 114°20′33.26″W)

The Kimberly hole was located approximately 2 miles northeast of Kimberly City on US Highway 50 on property owned by the University of Idaho extension farm. This area is a semi-rural area with domestic residences within a quarter mile of the desired drill pad. This site had the convenience of access from a major road, with easy water access from city fire hydrants within a mile. As previously stated the reason for drilling at Kimberly is that it lies on the margin of the Snake River plain, and has a relatively thin basalt cap overlying rhyolite.

Kimberly Drilling/Casing Plan

The original drilling and casing plan for the Kimberly hole is the same as the Kimama hole, with the exception that the original depth of the Kimberly hole was to be 6000 feet. The Kimberly hole is constructed to the constraints of the IDWR regulations.

On January 18, 2011 DOSECC Inc started clearing the site at the Kimberly and preparing a 100' x 100' drill pad. As it was middle of winter the soil was frozen in the morning and swampy in the late afternoon. The dirt road coming off of the University of Idaho's drive way to the drill pad also required geo-fabric and engineered soils. This increased pad preparation costs as it was not expected that this section would need work. Again a concrete box was installed to serve as a mini-cellar for the well head and annular preventer, and reserve pits we dug.

Kimberly Drilling History

Kimama hole is IDWR well tag D0057002 on permit number 859752, permitted to Utah State University Department of Geology Taking the lessons learned from the previous hole we decided that the core of the top 700 feet would be sacrificed in order to obtain a cased hole in a short amount of time so that the hole total depth could be accomplished within a budget. Two miles directly to the north of this site, the Snake River cut through the margin, and 300 ft of the overlying basalt can be seen. Being able to describe

this without drilling made it easier to sacrifice the core. Eaton Drilling and Pump Service were called out to air rotary a hole to 700 fbs. They spud Kimberly on January 26, 2011. The 12" hole was drilled to 40 fbs, and 8" casing installed and neat cemented in. Eaton then used an 8" hammer to drill to 703 fbs hitting the water table at 224 fbs. 703 feet of 4-1/2" x 0.25" wall threaded HWT casing was neat cemented in and Eaton was dismissed on January 31, 2011.

DOSECC Inc. then mobilized from the Kimama hole and proceeded to set up all equipment and was on the Kimberly site ready to drill out the casing on February 05, 2011. The progress of the hole relative to budgeted time is shown in Figure 9. We still drilled the entire hole with lost circulation as there was nothing

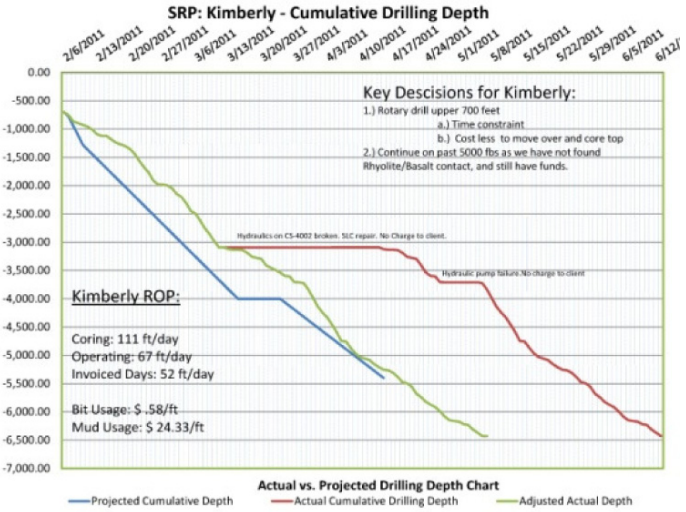

Figure 9. Kimberly depth vs. time and budget.

that we used for lost circulation material (LCM) that would get or keep returns.

Drilling HQ from the onset we drilled to the 3091 fbs depth on March 11, 2011 with only minor issues and trips for bits. The lithology alternated between rhyolite and basalts with 2 large inclusions of mudstone, sandstones and ash in the 875-950 and 975-1375 fbs levels.

Upon arriving at the T.D. of 5000 fbs, we were still in rhyolites. Still using NQ we drilled to 6422 fbs by June 13, 2011 whereupon the rods became stuck and the hole was terminated. Extensive logging through the rods was started on June 15, 2011. When logging through the rods was completed a wireline cutting service was called out and the free point of the rods was measured and a chemical cut of the NQ rods was done at 6377 fbs on June 16, 2011. Open hole logging commenced while pulling the NQ rods out. After multiple survey sweeps the hole had become unstable at 6280 fbs. Multiple trips in and out with the NQ rods were made and each time the hole was unstable and would not remain open. Eventually tripping into the cut off NQ rods was not available. Logging ceased on June 24, 2011 and 2-3/8" casing was run in the hole and crews tried to wash into the NQ rods up to June 28, 2011, including a trip to ream NQ to the cut interface. The casing was hung and its bottom was measured at 6270 fbs after tagging a bridge at 6280 fbs.

Kimberly Results

Total Depth	6422 feet
Total Footge Rotary Drilled	703 feet
Total Footage cored	5719 feet
Total Core Recovered	5727 feet (over 1.0 in certain zones with expanding clays)
Core Recovery	5727/5719 = 1.000
Core Recovery Total Depth	5727/6422 = .8917
Mud Consumption	$ 24.35 USD/ft. (Lost circulation at the onset of hole.)
Bit Usage	$ 4.20 USD/ft
Total Days	160.55 (Site Prep to demobilization, off site inclusive)
Days Offsite	38 (Equipment related not billable)
Days of Operation	122.5
Days Core Drilling	57.7
Days Ops not Drilling	38.8
Days Standby	15.7
Days on DOSECC Onsite Repairs	10.3
ROP when coring	111.3 ft/day
ROP While Operating	66.55 ft/day
ROP days invoiced	52.41 ft/day
Max Bottom Hole Temp While Drilling	54.6ºC

Results are shown in basic time breakdown as in Figure 10.

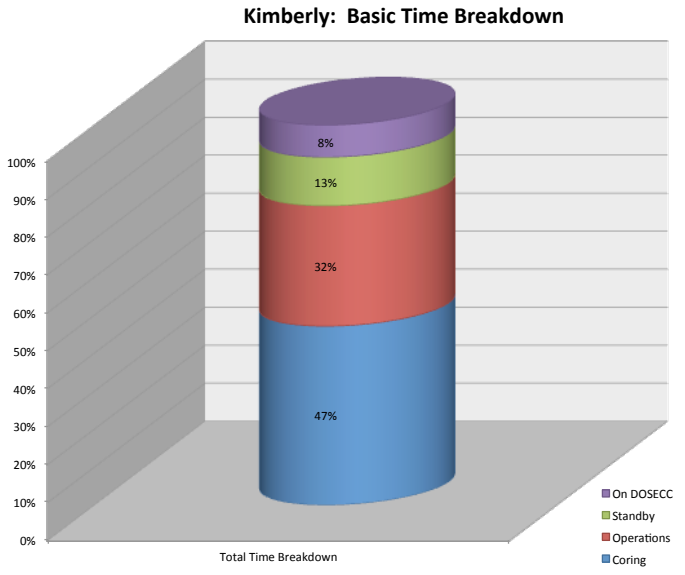

Figure 10. Kimberly time Breakdown.

Kimberly Lessons Learned

Although the drilling went fairly well on the Kimberly site, we were plagued with a couple of long term drill health issues that made this particular site drag on 38 days longer than it should. Backwards

analysis and observation of drilling procedures would indicate that high pressures can be formed inside the feed ram when drillers are stopping the head suddenly while fast feeding down in an open column. This was observed as drillers waiting for a tool to latch think it is caught up on a sanded-in barrel and are trying to force it to seat and latch. Although no calculations or measurements have been done to verify if these actions are exceeding designed pressure rating of the feed ram, one can see that it is probably not good on equipment. Therefore we have put in a procedure that helps avert such wear and tear on the feed system of our drill rigs. We also have a procedure to flush the entire hydraulics system after a major repair that involves any of 6 major areas: 1.) Leveling Jacks/ Mast Raise / Mast Dump rams 2.) Head rotation motor 3.) Feed cylinder 4.) Main hoist motor replacement 5.) Wire line motor replacement and 6.) Any of the 3 pumps replacement. Lastly in order to make the coring more effective, there still needs to be a better LCM choice for the high permeability that occurs in young basalts.

Mountain Home

(43° 4′11.57″N 115°53′34.61″W)

The Mountain home Site is located on the northwestern corner of the United States Mountain Home Air Force Base, approximately ¼ mile east of the Grandview gate. Drill pad access is restricted to those with valid U.S. Government identification. This site was allocated to the project by the 366th Civil Engineering Squadron Mission Support Group. Site preparation was also provided by the 366th mission support group.

Mountain Home Drilling/Casing Plan

The drilling/casing plan for Mountain is similar to the previous 2 holes with the exception that there is a known lake bed deposit beneath the basalt cap. 6-5/8" casing was drilled to 530 fbs and cemented. The intermediate temporary 4-1/2" casing would be landed at a depth of 1930 fbs.

Mountain Home Drilling History

Mountain Home test 1 on IDWR geothermal application 61-GR-08 was spudded on June 24, 2011. Eaton Drilling and Pump Services drilled and set a 40 foot pressure grouted surface seal then drilled to 530 fbs through the basalt cap to the depth where the lake sediments were believed to be. DOSECC Inc. moved on the hole and started coring from 530 fbs to 1967 fbs through sand and intermittent clay layers. At this depth the rods became stuck and drill crews worked for several days to get the operation moving forward. We decided it would be more cost effective to cut and remove the drill rod, start a new hole and rotary to 2000 fbs than try to work this hole 2 more days. Upon reaching 2030 fbs in MHAFB test 2 we still had not drilled out of the lake deposited material. The temporary casing was landed and HQ core was drilled out the bottom. HQ coring continued with returns to 3753 fbs on October 29, 2011. NQ coring commenced after landing the HQ as a temporary casing string. Drilling was suspended over Christmas and New Year's from December 8, 2011 – January 15, 2012 for budget review. On January 15, 2012 the geophysical surveys started and lasted through January 22. NQ coring commenced and advanced to 5640 on January 25, 2012 where lost circulation began to develop and by 5726 the next day there was an artesian up flow of 11 gal/min. Water sampling was accomplished and drilling continued with barite mud to balance

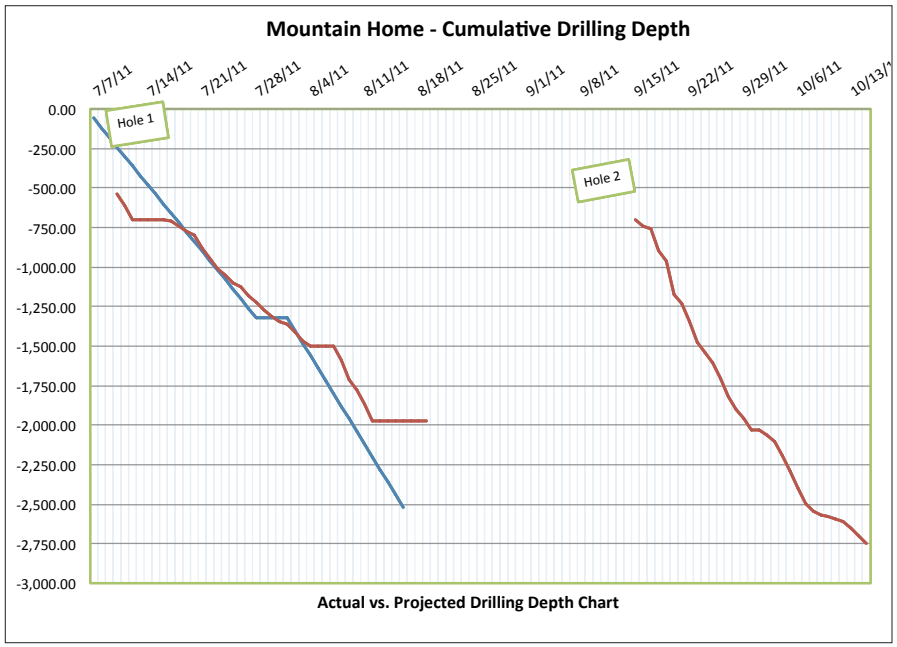

Figure 11. Mountain Home drilling depth Phase I.

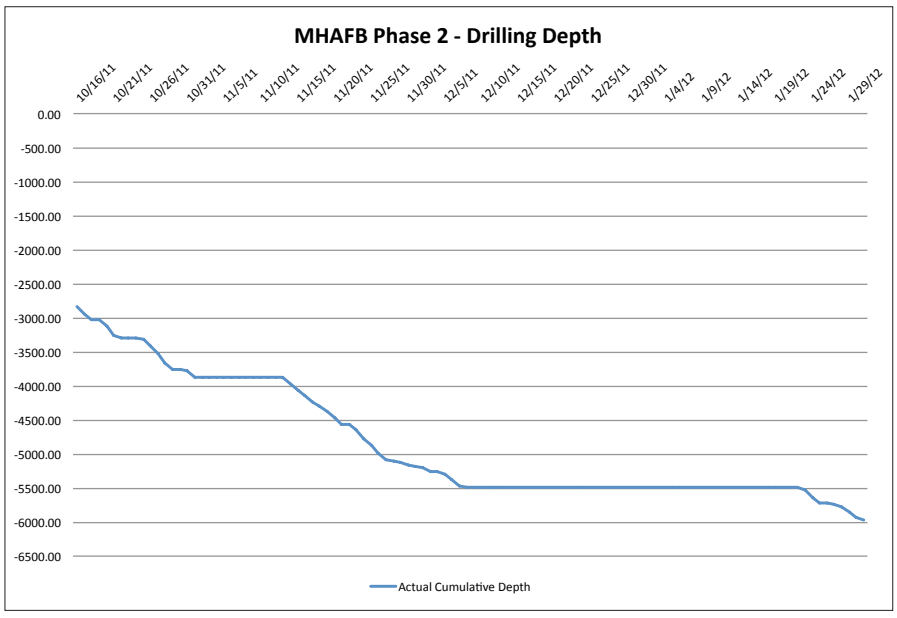

Figure 12. Mountain Home drilling depth Phase II.

the upwards pressure. NQ coring advanced and the hole T.D. was called at 5976 on January 31, 3012 due to budget constraints. Drilling progress at Mountain Home is shown in Figure 11.

Mountain Home Results

Total Depth: Test 1 0-1967 Test 2 0-5976	1967 feet 5976 feet
Total Footage Rotary Drilled	2560 feet
Total Footage cored	5383 feet
Total Core Recovered	5104 feet
Core Recovery	5104/5383 = .9482
Core Recovery Total Depth	5104/7943 = .6426
Mud Consumption	$ 12.15 USD/ft.
Bit Usage	$ 2.90 USD/ft
Total Days	216 (Site Prep to demobiliza tion, off site inclusive)
Days Offsite	78
Days of Operation	138
Days Core Drilling	72.27
Days Ops not Drilling	49.51
Days Standby	21.53
Days on DOSECC Onsite Repairs	5.14
ROP when coring	100.7 ft/day
ROP While Operating	63.0 ft/day
ROP days invoiced	49.5 ft/day
Max Bottom Hole Temp While Drilling	147°C

Results are shown in basic time breakdown as in Figures 12 and 13.

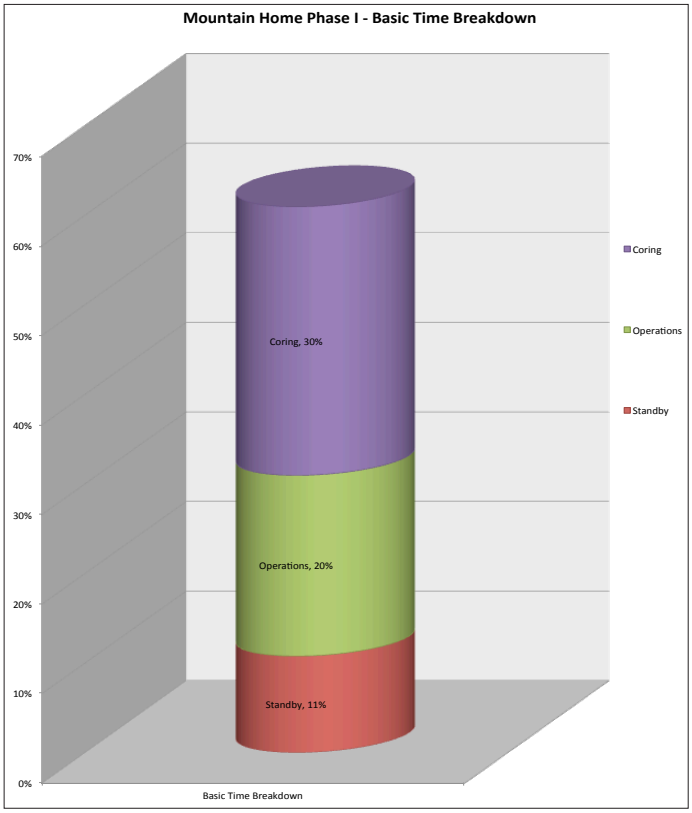

Figure 13. Time breakdown Mountain Home Phase I.

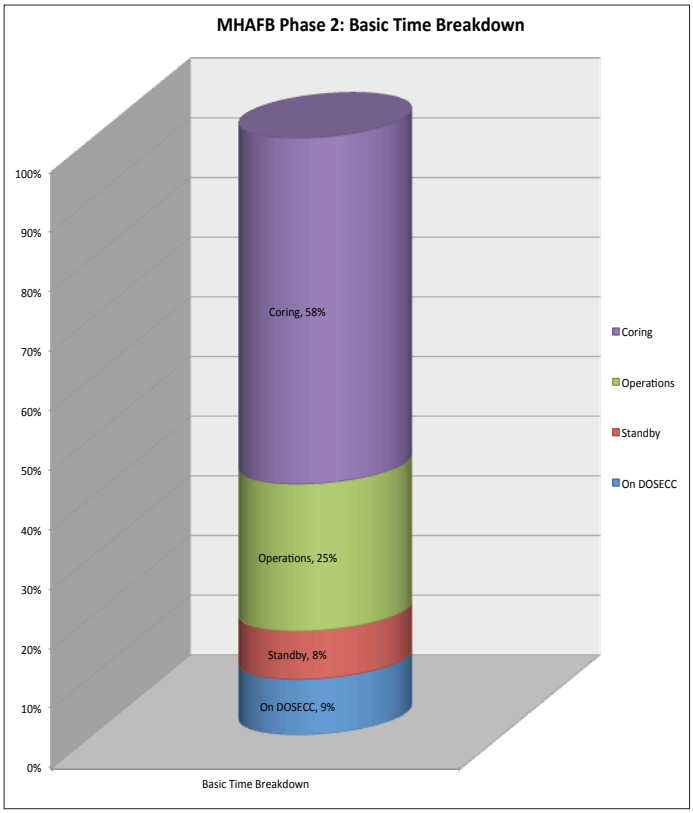

Figure 14. Time breakdown Mountain Home Phase II.

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