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Improvement in Rate of Penetration in FORGE Drilling Through Real Time MSE Analysis and Improved PDC Technology

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ABSTRACT

One of the biggest handicaps of the Geothermal Drilling industry is the poor performance on ROP and the lack of proper data collection while drilling, data integration, and analysis of such data, when compared with the Oil and Gas Industries. The lack of this essential engineering, well planning, and construction tool seemingly adds a significant amount of time to the 12-days additional non-productive time (NPT) at average per well while drilling geothermal wells versus oil and gas wells, thus leading to higher well costs. Geothermal Resource Group (GRG) has recently been involved in the planning and drilling of the wells for the FORGE Utah with the University of Utah and was able to successfully implement the use of MSE_{Total} approach with PDC bits

The Utah FORGE Project drilled one well in 2017 and then three more wells in 2020/2021. The results described in this paper show a 56-65% reduction in actual days required to drill to the same depth from the first well to the fourth well. Additionally, the on-bottom, drilling-only hours needed to reach 9,000-ft was reduced by 62% from the second well to the fourth well.

1. INTRODUCTION

Geothermal, hard rock drilling has intrinsic challenges typically not encountered in conventional oil and gas (O&G) wells. Wells are engineered to target formations with high internal temperatures in the Geothermal Industry as opposed to the O&G Industry where formations are targeted for their ability to produce oil or gas. The high temperatures needed in Geothermal wells are often found in deep, ultra-hard, basement rock such as granite, while O&G wells drill relatively softer sandstone, limestone, and shale. Traditionally, due to the hardness of the granite, geothermal well construction costs have been much higher than O&G wells due to slow ROP and short drill bit life. Additionally, with far fewer geothermal wells being drilled each year compared to O&G, the Geothermal Industry has been falling behind technologically. The Utah FORGE Project set out to change the paradigm and trial the latest in drill bit technology as well as implement O&G Industry leading real-time drilling data analytics, specifically the use of mechanical specific energy (MSE) to optimize parameters.

The Utah FORGE Project drilled one well in 2017 and then three more wells in 2020/2021. All the wells were within a few miles of each other in western Utah and involved drilling predominately 30-50-kpsi granodiorite. In chronological order, the wells were 58-32 (well #1), 16A 78-32 (well #2), 56-32 (well #3), and 78B-32 (well #4). Well #1 was drilled in July 2017 mostly with roller-cone bits. One attempt was made to drill with a fixed-cutter polycrystalline compact (PDC) bit and one attempt was made with a roller-cone/PDC hybrid bit design. Roller-cone bits outperformed other bit types on well #1. The Utah FORGE Project drilled three more deep wells in 2020 and 2021. Lessons learned from one well to the next were implemented. PDC bit and diamond cutter technology improved significantly from 2017 to 2020. The Project team decided to implement the new bit technology on the 2020/2021 wells.

The Utah FORGE Project team has drilled four wells. Figure 1 compares the Actual Days of drilling versus the Hole Depth drilled. All non-productive time included. To a depth of approximately 7,500 ft. MD, well #2 showed a 14% reduction in days required compared to well #1. Wells #3 and #4 showed a 56-63% reduction in total days required compared to well #2, illustrating the gains made by implementing lessons learned well-to-well.

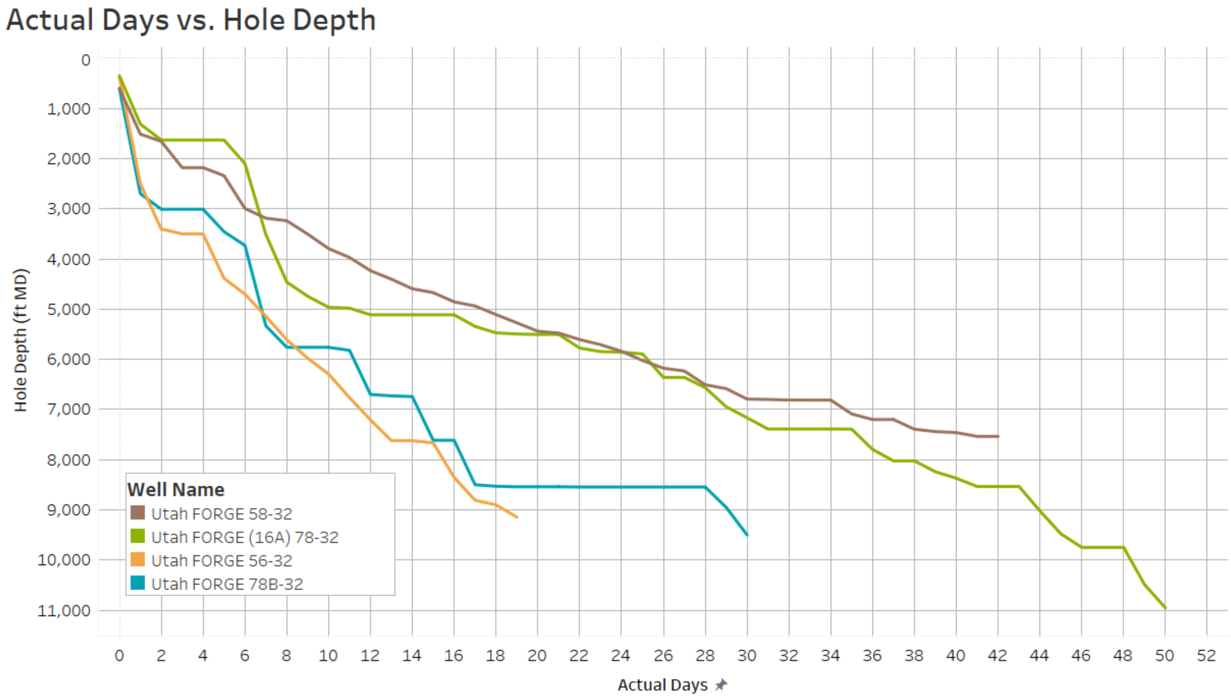

Figure 1: FORGE Utah Wells - Days vs Depth - Multi wells comparison

Figure 2 removes all non-productive time from the Actual Days vs Hole Depth data leaving only On-Bottom Hours versus Hole Depth to demonstrate the actual drilling rate of penetration gains. Well #2 took 273 on-bottom hours to achieve a depth of 9,000 ft. Well #3 reduced the number of on-bottom hours needed to 9,000 ft. by 28% requiring only 197 hours. Well #4 further reduced the hours need by requiring on 104 hours to 9,000 ft. Well #4 reduced hours required by 47% over well #3 and 62% over well #2, despite the granite top being progressively shallower with each well (more granite to be drilled). Two key factors leading to such significant ROP improvements, well-to-well, were the use of mechanical specific energy (MSE) to ensure optimal drilling efficiency and drill bit design selection (real-time) as the wells were being drilled.

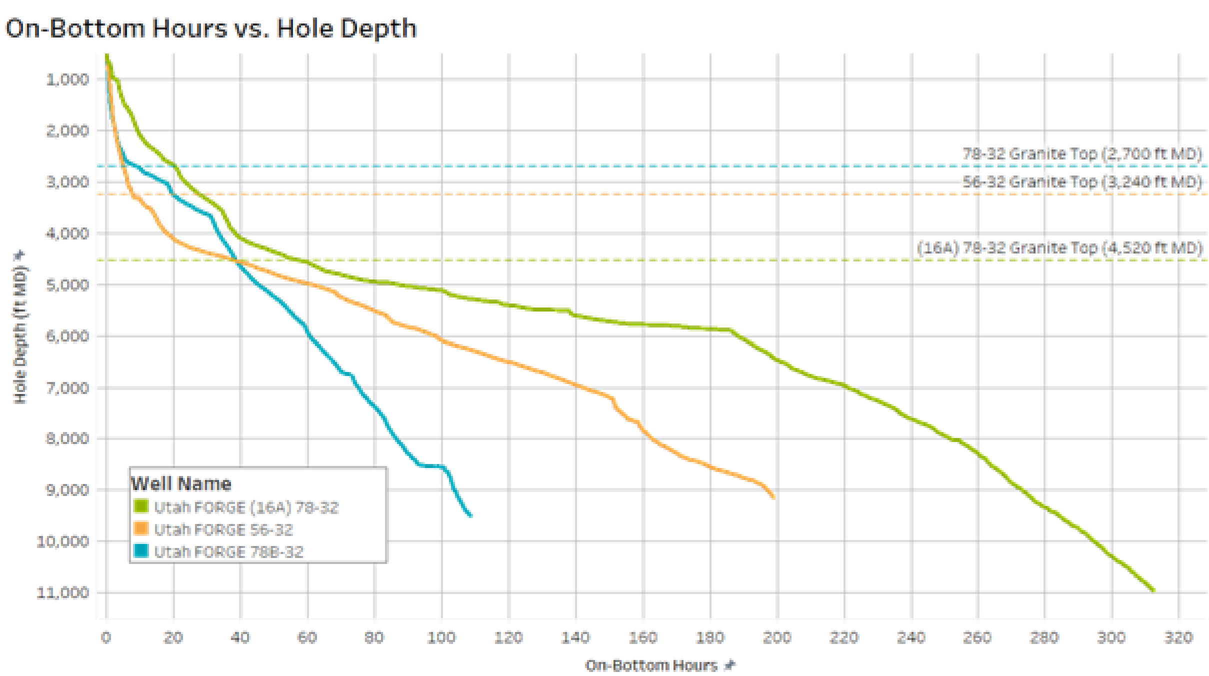

Figure 2: FORGE Utah Wells On-Bottom Hours vs Depth - Multi wells comparison

2. MECHCANIL SPECIFIC ENERGY (MSE)

MSE is a numerical value used to understand how efficiently a system is drilling. It is the unit of energy used per unit of rock removed. The formula for calculating MSE incorporates pertinent drilling parameters being input into a system (weight on bit, revolutions per minute, and torque) and relates it to the performance output of the given system (ROP) (Figure 3). The lower your relative MSE value, the more efficiently the drilling system is removing rock. Thus, less energy being expended (wasted) by something other than rock-removal. Tracking MSE through various depths and at various parameter combinations is vital to identify the presence of drilling dysfunction which could lead to low ROP or bit/BHA damage (Figure 4).

$$MSE_{psi} = \frac{480 \times TOR \times RPM}{Dia^2 \times ROP} + \frac{4 \times WOB}{\pi \times Dia^2}$$

Figure 3: MSE Equation

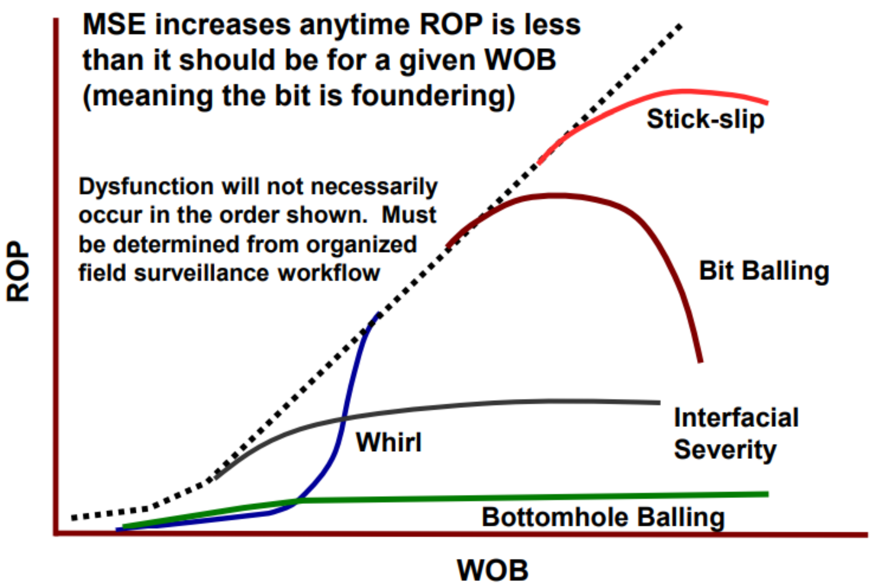

Figure 4: Identifying the presence of dysfunction

2.1 Parameter Step-Test for Optimal MSE

As part of the overall performance improvement effort, the Utah FORGE Team performed parameter step-test throughout the well to ensure dysfunction was minimized and efficiency was maximized. A step-test is performed by methodically varying a specific parameter in incremental steps and watching for changes in MSE. The parameters changed during a step test included top-drive RPM or WOB. The fundamental strategy during a step test is to change one parameter, wait a few seconds, and see which direction MSE moves. If MSE is reduced after the parameter step change, then the system has begun drilling more efficiently and the new parameter value should be preferred over the old value. If MSE increases after the change, the system is drilling less efficiently, and the parameter should be returned to the original value or changed to another step to further check for optimal parameters. Figure 5 shows an example of a rotary speed step-test and the corresponding MSE reaction. MSE increased indicating the system is now drilling less efficiently, likely has more dysfunction, and energy is being lost to something other than rock-removal. Figure 6 is an example of a WOB step-test. The MSE can be seen to reduce with each WOB step increase meaning the system is gradually drilling more efficiently.

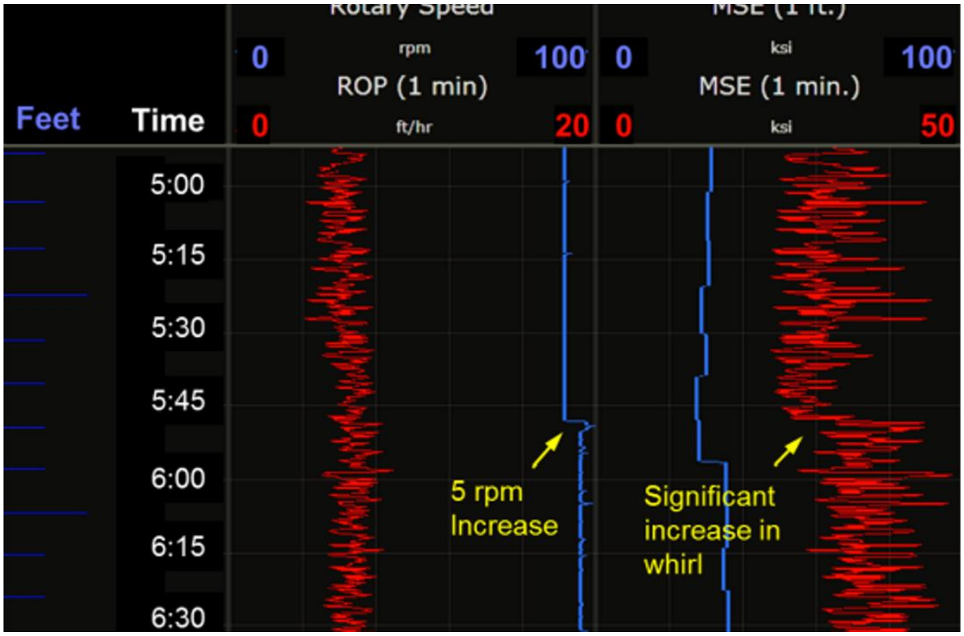

Figure 5: Rotary Step-Test Example

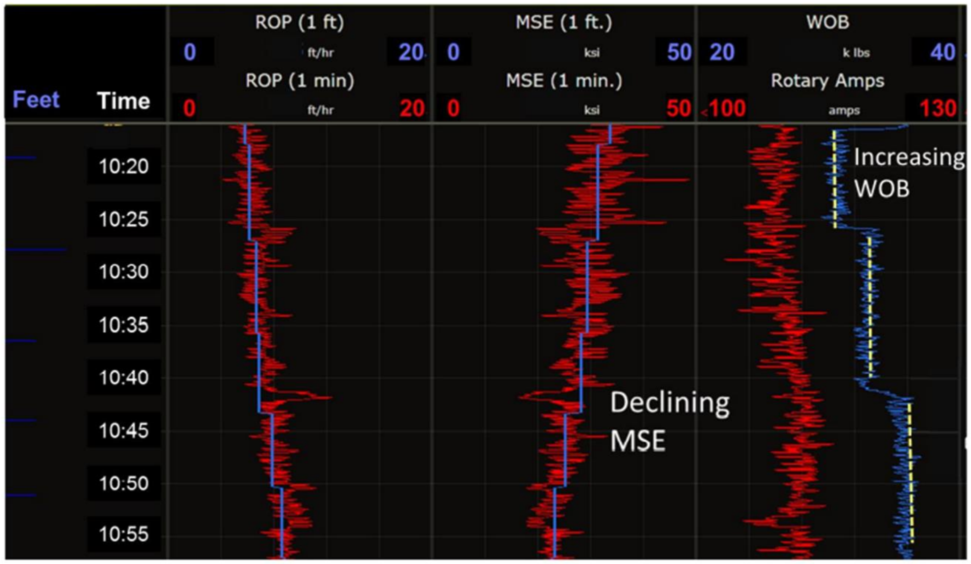

Figure 6: WOB Step-Test Example

2.2 Step-Test Examples from Utah FORGE Wells

Parameter Step-Testing to find optimal MSE was done more deliberately on well #4. Figure 7 shows two examples of parameter step-tests performed. The step-tests are highlighted by the red circles.

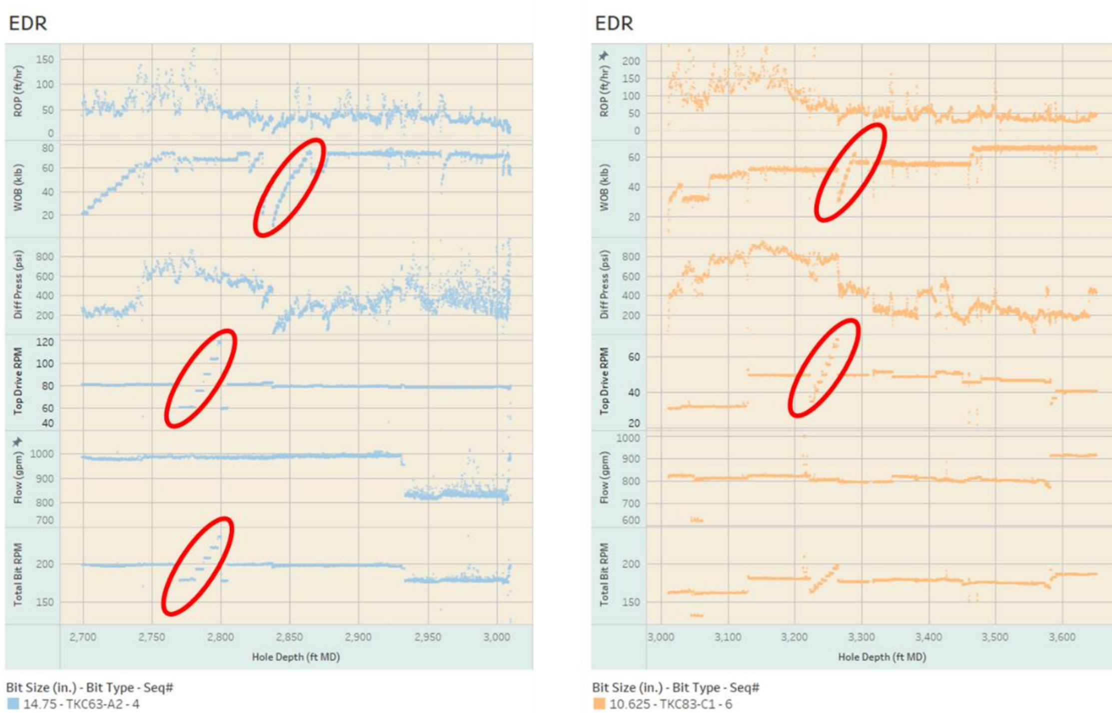

Figure 7: Examples of Step-Tests from well #4

The use of step-testing to find optimal MSE is particularly important when drilling long intervals in hard, homogeneous rock such as the granite drilled by Utah FORGE. MSE is a function of the force needed to destroy and remove a given rock, so if formation changes are present then MSE will change regardless of a parameter change. The granite drilled by Utah FORGE was relatively homogeneous in compressive strength through the interval so changes in MSE could be easily linked to dysfunction rather than a formation change. This fundamental understanding led to dramatic improvements in ROP and footage achieved for a single drill bit. Figure 8 shows the ROP, footage, and parameters used on the longest bit run from well #2. Figure 9 shows the ROP, footage, and parameters used on the longest bit run from well #4. The record bit from well #4 drilled 2,110 ft. in 27.9 on-bottom hours and the record from well #2 drilled 742 ft. in 14.2 on-bottom hours. The bit on well #4 drilled 184% more footage but only took 96% more hours. The Utah FORGE team had confidence to run higher parameters, on well #4, because MSE was more closely monitored therefore damage due to drilling dysfunction was mitigated.

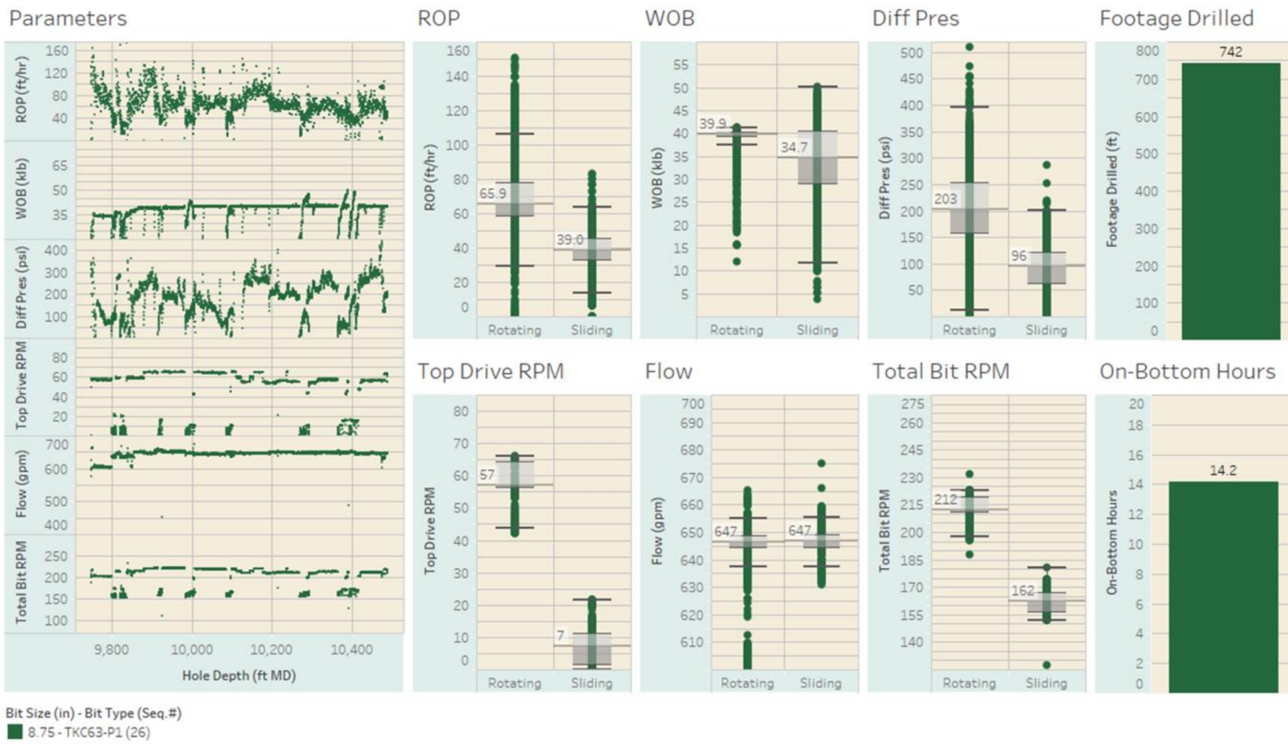

Figure 8: Performance from record footage run on well #2

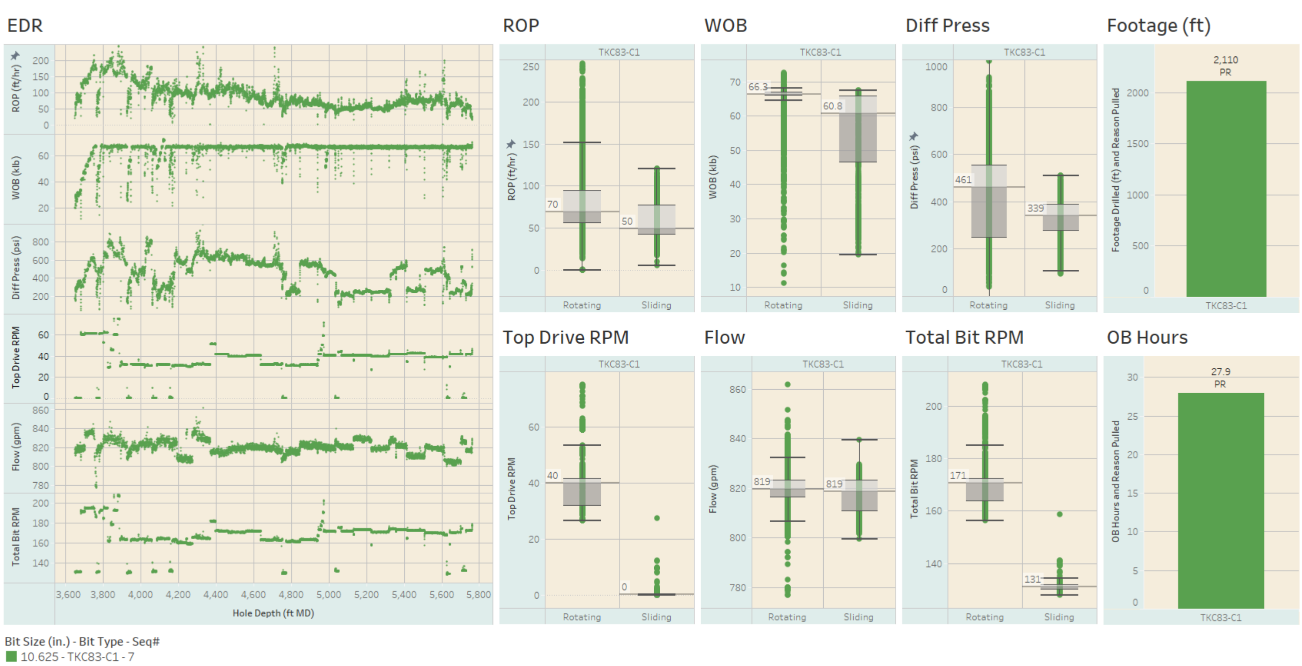

Figure 9: Performance from record footage run on well #4

3. IMPROVED PDC TECHNOLOGY

Prior to well #2 of the Utah FORGE project, roller-cone drill bits were the performance leader in hard-rock drilling. PDC cutter technology had not evolved enough to withstand drilling ultra-hard, high compressive strength rock. Figurer 10 shows the relative durability improvements made in PDC diamond cutter technology. Cutters are now at a level of durability sufficient to withstand the hash drilling environment of geothermal applications.

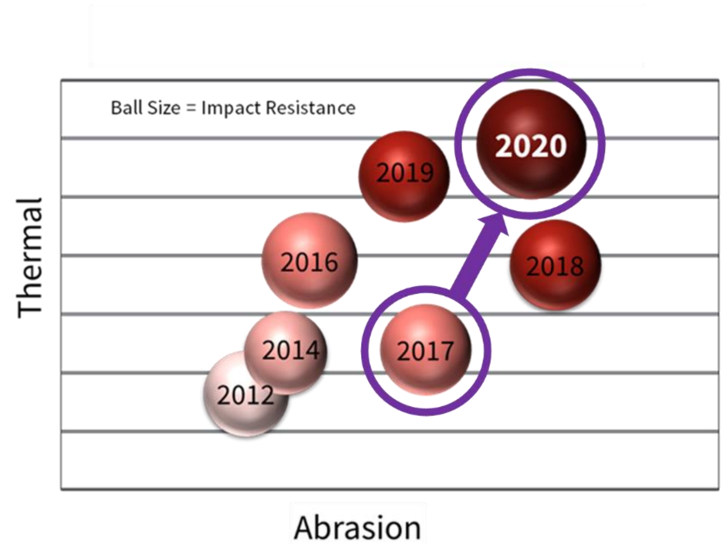

Figure 10: Relative improvement in thermal stability, abrasion resistance, and impact resistance of PDC diamond cutter technology

4. CONCLUSIONS

Establishing a real time MSE monitoring system and utilizing the latest in PDC cutter technology have allowed a significant reduction in the time required to drill well. Utah FORGE realized a 56-63% reduction the Actual Days needed to drill a Geothermal well. They also realized a 62% improvement in on-bottom hours, highlighting the improvement specifically in drilling performance.

This improvement in performance can significantly reduce the required days to drill a geothermal well and therefore will lower the cost for future geothermal projects.

4. ACKNOWLEDMENTS

We want to thank Fred Dupriest and Sam Noynaert from Texas A&M University for all their daily support, and the excellent MSE training. Their insistence that everyone involved in the drilling process, from the sample catcher to the project manager must take this training proved to be invaluable. It was perfectly clear that for the MSE real time monitoring and limiter redesign to be properly implemented and achieve this performance improvement, everyone needs to be on board. It is quite common in geothermal industry to hear "*we tried MSE drilling with poor results"* regarding MSE real time monitoring approach to ROP improvement and we can only assume it was because not everyone was on board with the concept and things were done in a way that limited the effectiveness of the approach.

Our experience indicates that the improvement on ROP was not so much a technology transfer as it was *"a knowledge transfer"*, With the recent advancement in PDC technology, all that is needed is to learn how to use such existing technology more efficiently.

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