Collaborative and Holistic Applications Drive Record Drilling Performance in Mak-Ban Geothermal Field, 2020-2022

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ABSTRACT

Philippines pioneered the geothermal development in Southeast Asia and consistently remained as one of the largest producers in the world since the birth of the industry in 1971. Philippine Geothermal Production Company, Inc. (PGPC) operates both Tiwi and Mak-Ban geothermal fields. With over 300 wells drilled since its exploration days, PGPC maintained its significant load share in the Luzon grid up to present.

In fields such as Mak-Ban, wells as deep as 3,000m. are drilled in order to tap this renewable resource. From 2020-2022, PGPC executed an 11-well drilling campaign comprising of 9 deep production wells and 2 multilateral injection wells, with all wells now in the system. Seven out of ten deepest wells (>3,000m) in Mak-Ban were drilled in this campaign. This campaign resulted to several records; fastest well drilled 3,611m in 23.9 days, fastest daily Rate of Penetration (ROP) of 523m per day, and lowest Non-Productive Time (NPT) of 3% despite of new well design challenges.

This paper aims to share the journey of PGPC Drilling Team in improving drilling performance by adapting a collaborative and holistic approach from well planning, operational alignment, design improvement and technology selection. Drilling performance metrics from recently concluded 9-well Mak-Ban drilling campaign and the previous 2002-2004 drilling campaign were compared to show the success and improvement. These metrics are: (1) Days drilled vs Actual Depth reached, (2) Rate of Penetration, (3) Target depth reached vs Planned depth, and lastly, (4) Drilling Non-productive time.

1. BACKGROUND

1.1 Makiling-Banahaw (Mak-Ban) Geothermal Field

As of January 2023, Philippines ranks 3rd of the biggest geothermal producers in the world with its installed capacity of 1,935MW, just behind Indonesia (2,356MW) and USA (3,794MW) (ThinkGeoEnergy, 2023). Philippine Geothermal Production Company, Inc. (PGPC), a 100% Filipino owned corporation operates two (2) of the active geothermal fields in the Philippines today and accounts for the 682MW of installed capacity.

Philippine Geothermal Inc. (PGI), a local subsidiary of Unocal Corporation, which was later acquired by Chevron on 2005 would eventually be known as PGPC under SM Investments Corporation. PGPC (then PGI) pioneered the geothermal development in the Philippines in the 1970's and continues to operate both Tiwi and Mak-Ban Geothermal fields. As of 2020, generation from these plants accounts for ~66% of the electricity generated from geothermal energy on the Luzon Grid (PGPC, 2023).

Mak-Ban geothermal steam field is situated in the provinces of Laguna and Batangas in the Luzon area (Figure 1). Discovery and development of this field started in 1974 and commenced commercial operations by 1979. It has a contract area of 4,323 hectares with more than 100 wells drilled for both production and reinjection purposes.

Figure 1 Mak-Ban Geothermal field is located in the northern part of the Philippines in Luzon area.

1.2 Scope and definitions

Drilling performance comparison will be focused on two campaigns which happened next to each other but ~20 years apart. Campaign A and B will refer to the 2002-2004 and 2020-2022 campaigns, respectively. Both campaigns drilled in the same location and sector, although on different pad locations. While both campaigns drilled multi-legged wells - one for the previous campaign and two for the present, only the single leg producers were included in the data set, resulting to 9 wells per campaign.

Some assumptions on the metrics presented below:

- Rate of Penetration (ROP) means overall spud to rig release, including all the flatspot activities like casing and cementing, and completion tests.
- Drilling days covers all drilling activities spud to rig release.
- Total Depth (TD), both planned and actual is measured drilled depth along the direction of the well.

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- Non-productive time (NPT) commences upon the discovery of issue until the time it takes to reach the depth at which the issue was first encountered.

2. DRILLING CAMPAIGN

2.1 2002-2004 Drilling Campaign

Previous to this campaign, there was continuous drilling on the 90's. This 2002-2004 campaign is a 10-well drilling campaign, one of which is a multi-legged well. It aimed to target "deep" reservoir and provide additional steam to the plant. Particular to this campaign is the execution of two Tieback operations in order to transfer the pressure containment shoe to the 13 3/8in casing string to satisfy the higher pressure requirement due to the deep targets. Results of the campaign is shown in Table 1.

Table 1 2002-2004 Drilling Campaign showing total depth, days drilled, and ROP

Well Name	Total Depth, m	Drilling Days	ROP, mpd	Planned Depth Reached?
A-1	3424	49.0	70	✓
A-2	3117	44.4	70	✓
A-3	3012	38.4	78	✓
A-4	2844	45.0	63	✓
A-5	3109	46.2	67	✓
A-6	2900	34.4	84	95%
A-7	3109	26.2	119	✓
A-8	3170	55.6	57	✓
A-9	3347	33.1	101	✓
Average:	**3115**	**41.3**	**79**	

Despite of the numerous challenges encountered on this campaign, all wells reached at least 95% their target planned depth. Wells were drilled between 2844-3424m, with an average depth of 3115m.

Wells were drilled in 26.2-55.6 days with an average drilling days of 41.3 days. With an average closer to the high side of the range, there is still much room for improvement. Similar is observed with ROP, with an average of 79mpd which is nearer to the lower end of the ROP range of 57-119mpd.

Overall, the 2002-2004 drilling performance is still above average with record drilling of Well A-7 - ROP of 119mpd, drilling and completing a 3109m well in just 26.2days.

The campaign encountered a lot of drilling challenges with several stuckpipe incidents on all the wells. A stuckpipe incident occurs when the drilling assembly can neither move up or down, nor rotate. There are several reasons for stuckpipe incidents like hole pack-off either from poor hole cleaning or formation instability, well profile, among others. Sometimes a stuckpipe may result to a Fish left in hole when not freed. A "fish" or Lost-in-hole (LIH) refers to any drilling assembly that cannot be retrieved due to untoward scenarios. 5 out of 9 wells had fish left in hole. Presented in Table 2 is the stuckpipe occurrences per well in the campaign.

Table 2 All 2002-2004 Drilled wells had stuckpipe with 5 having Fish left in hole

Well Name	Stuckpipe ?	w/ Fish
A-1	✓	✓
A-2	✓	✓
A-3	✓	
A-4	✓	✓
A-5	✓	✓
A-6	✓	
A-7	✓	
A-8	✓	
A-9	✓	✓

2.2 2020-2022 Drilling Campaign

2020-2022 drilling campaign comprises of an 11-well program with 2 multi-legged wells. It aimed to target the "deep" reservoir too, but also needed to isolate the highly permeable shallow reservoir which became the conduit for cold fluid inflow over the years. The change in the well design is shown in Figure 2

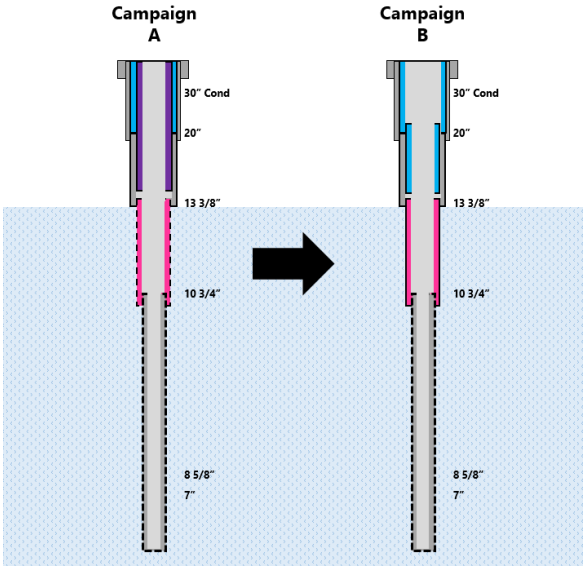

Figure 2 Differences in the well design of 2002-2004 and 2020-2022

The isolation of the "shallow" reservoir is the first challenge for this campaign. This is a huge cementing challenge to say the least and would require specialty chemicals that are likely unavailable in the region. Cementing the reservoirs will consume more cement than normally allocated per well so inventory of cement and additives need to be managed carefully especially for a geographically-isolated country like Philippines. In effect, this flatspot activity will also add to the rig and contractor time which is the most expensive of all drilling expenses.

Second well design challenge is to optimize the method of transferring the pressure containment shoe to the 13 3/8in shoe. Previously, this was done by executing 2 tieback casing and cementing activities which are not only time consuming but also high risk.

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Next big challenge is how to address the stuckpipe scenarios resulting from poor hole cleaning brought about by the depth and inclination of the wells. Good hole cleaning not only reduce stuckpipe incidents but also improve drilling efficiency because the drill bit will be drilling new formation instead of regrinding the cuttings.

There were other several challenges embarking on this campaign. As there were no more drilling of wells in Mak-Ban until this 2020-2022 campaign. This huge gap in drilling presented many challenges particularly in team composition, all of which, though experienced personnel do not possess institutional knowledge or familiarity in drilling Mak-Ban wells. In order to prepare for the upcoming campaign, the PGPC Drilling and Workover (DW) team studied the previous campaign intensively and aimed to emulate the performance particularly of Well A-7 and address the potential stuckpipe scenarios. The team also aimed to reduce the overall NPT which was averaging at 28% to bring down drilling costs. Materials and service costs have increased tremendously over the years, so improved drilling efficiency would be necessary to reduce further cost impact. Another challenge which was not expected by the team was drilling in a "bubble" due to Covid-19 pandemic. This resulted in additional significant cost to the operations, issue on global logistics, increase in prices, and personnel anxiety.

Despite these challenges, PGPC DW team was able to complete the drilling campaign earlier than expected. Results are shown in Table 3:

Table 3 2020-2022 Drilling Campaign Results

Well Name	Total Depth, m	Drilling Days	ROP, mpd	Planned Depth Reached?
B-1	2878	47.4	61	86%
B-2	3254	47.7	68	✓
B-3	3214	35.2	91	✓
B-4	3264	37.8	86	✓
B-5	3222	31.4	103	✓
B-6	3548	30.3	117	✓
B-7	3506	28.8	122	✓
B-8	3353	24.3	138	✓
B-9	3611	23.9	151	✓
Average:	**3317**	**34.1**	**104**	

There were several hiccups in drilling the first well B-1 terminating due to rig top drive issue at 86% of its target depth. On the stuckpipe incidents, no major event was encountered and all were freed immediately after getting stuck. B-8 stuckpipe was due to differential sticking which was freed immediately after applying air on the pipe.

Table 4 Stuckpipe 2020-2022

Well Name	Stuckpipe ?	w/ Fish
B-7	✓	
B-8	✓	

3. DRILLING PERFORMANCE

3.1 Days drilled vs Actual Depth Reached

Figure 3 is a simple plot for the Total Depth vs Days it took to complete the well, showing the relative performance for wells drilled in the same depth over same period. The plot below shows that majority of the deepest and fastest wells drilled were part of the 2020-2022 Campaign. It can also be seen that the performance of the present campaign improved with each well drilled – a result of the intensive look back and re-aligning strategies as each well is completed.

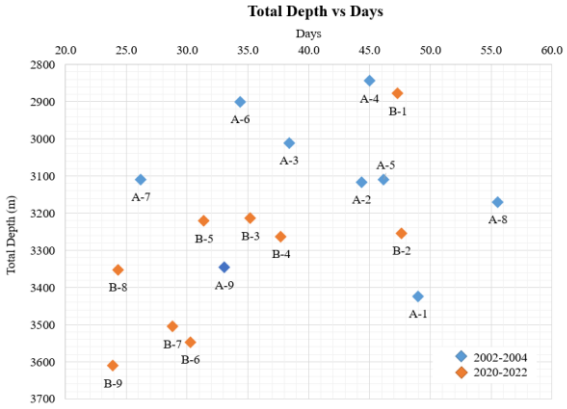

Figure 3 Total Depth vs Days drilled of the 2 campaigns showing that 2020-2022 wells were drilled deeper and shorter

Presented in Figure 4 is the detailed Days vs Depth (DvD) graph of the two campaigns being compared. Performance of each section per well and also per campaign are shown on this graph.

The previous campaign's drilling graph was more crowded towards the right side which is the low end of the performance. It is also widely spread which means that their performance swings between good and bad and is quite unpredictable. This is a nightmare with performance tracking, cost estimation, warehouse and inventory planning since adequate buffer both in schedule and materials need to be in place for the "bad" times but may also suitably end up underutilized resulting in cost expense during "good" times.

In contrast, in the present campaign, with the exception of the 1st and 2nd well, the performance are closely spaced and more predictable. Furthermore, the graphs are crowded to the left which means the present wells were drilled on a shorter duration. The 2nd well exhibited the good performance until it encountered a lost cone incident which necessitated a sidetrack.

It can be observed that drilling in the 2020-2022 campaign exhibits a consistent steep slope which means good performance. In addition, it can also be seen that a long flatspot occurs consistently at all wells at about ~1800-2000m, this is mainly due to the cementing challenge inside the reservoir.

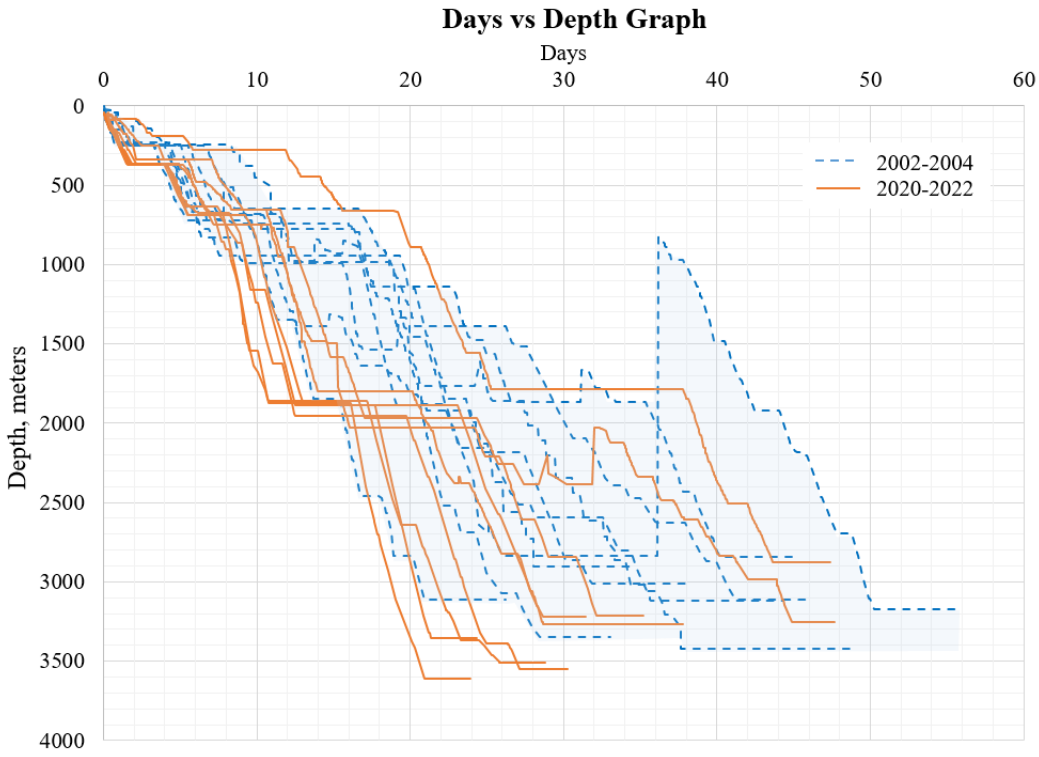

Figure 4 Days vs Depth graph of 2002-2004 vs 2020-2022 Drilling Campaign shows significant improvement

3.2 Rate of Penetration

One of the most common metric for measuring drilling performance is the rate of penetration, which is the amount of depth drilled over a certain period, in this case, in meters per day. The graph in Figure 5 shows the overall ROP including the flatspots or the non-drilling activity and this is computed as follows:

$$ROP = Total\ Depth \div Days\ (Spud\ to\ Rig\ Release)$$

In order to improve ROP, a lot of factors need to be taken into consideration; (1) the rate at which drilling happens, (2) the time it takes to complete the flat spot activities like casing, cementing, and completion test, and (3) the down times called non-productive time like rig and equipment repair and addressing lost circulation.

The 2020-2022 Campaign average ROP increased by 32% from 79mpd to 104mpd as compared to the 2002-2004 campaign, with a record ROP of 151mpd for the last well of the campaign vs their previous record of 119mpd. The longest meterage drilled per day was at record-high 523m for the same well.

Looking at the graph in Figure 5, the previous campaign showed a relatively flat ROP performance except for the stellar A-7 and A-9 performance. These two wells were studied for the best practices to be emulated for the 2020-2022 campaign.

In comparison, the ROP for the present campaign showed an upward increasing trend as more wells are drilled – improvement was being done by learning from each well being drilled.

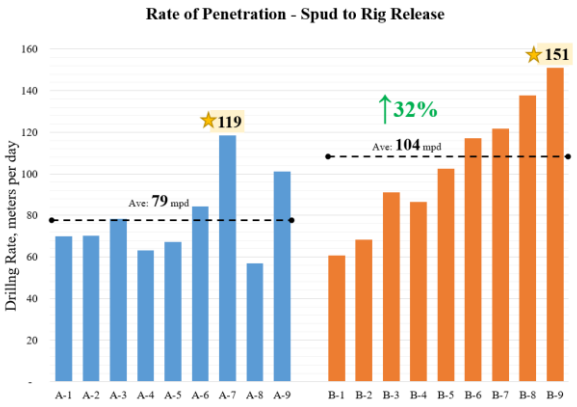

Figure 5 2020-2022 campaign has a 32% better ROP from Spud to Rig Release

3.3 Total Depth vs Planned Depth

In terms of reaching the planned depth, the previous campaign did a better job than the present campaign. The 2002-2004 campaign reached their target TD for all wells except one, although that well was only 5% short of target. On the other hand, one well in the present campaign reached only 86% of its target TD due to some rig top drive issues. All others also reached their target depth. Table 5 shows the summary.

Table 5 Planned Depth vs Actual Depth Reached

2002 - 2004	Planned Depth Reached?	2020 - 2022	Planned Depth Reached?
A-1	✓	**B-1**	86%
A-2	✓	**B-2**	✓
A-3	✓	**B-3**	✓
A-4	✓	**B-4**	✓
A-5	✓	**B-5**	✓
A-6	95%	**B-6**	✓
A-7	✓	**B-7**	✓
A-8	✓	**B-8**	✓
A-9	✓	**B-9**	✓

In terms of depths reached, the average depth for this campaign is at 3317m, only deeper by ~200m. The deepest well comes in at 3611m which is the second deepest well in Mak-Ban field, short only by 12m from Bul-068. 7 out of 10 deepest wells in Mak-Ban were drilled in this campaign, while 2 are from the previous (A-1 and A-9) drilling.

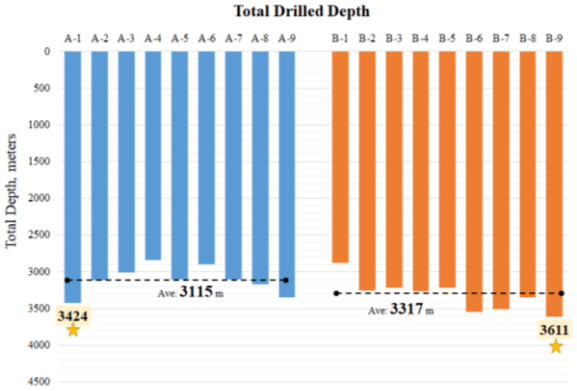

Figure 6 Total Drilled Depth between campaigns does not vary significantly, with the 2020-2022 only ~200m deeper

3.4 NON-PRODUCTIVE TIME

Non-productive time (NPT) are undesirable events that do not provide any benefit to the drilling as a whole. They cost the operation time and money but do not advance the drilling as a whole. Most of the time these are mechanical issues, like equipment downtimes and repairs, waiting on something like a bad weather to ease out or some materials that did not arrive on time, or time spent in addressing loss circulation.

Table 6 Stuckpipe Summary 2002-2004 vs 2020-2022

2002 - 2004	Stuck pipe?	w/ Fish	2020 - 2022	Stuck pipe?	w/ Fish
A-1	✓	✓	**B-1**		
A-2	✓	✓	**B-2**		
A-3	✓		**B-3**		
A-4	✓	✓	**B-4**		
A-5	✓	✓	**B-5**		
A-6	✓		**B-6**		
A-7	✓		**B-7**	✓	
A-8	✓		**B-8**	✓	
A-9	✓	✓	**B-9**		

One of the major drivers of NPT from previous campaign is the stuckpipe events. This was one of the main focus that needed to be addressed in the 2020-2022 campaign. In order to improve hole cleaning efficiency even in deviated deep wells, aerated drilling technology was brought in. By calibrating the software used for geothermal application, parameters were set to optimize hydraulics, improve drilling efficiency and mitigating stuckpipe situations due to poor hole cleaning. In effect, only minor events were encountered in the present campaign and were immediately freed – no spending days trying to free stuck pipes nor leaving expensive fish in the hole.

Another major driver in NPT is addressing losses in the shallow section by putting in cement plugs. In the present campaign, losses were addressed through pseudo-thixotropic cement and by employing aerated drilling in the shallow section, thereby reducing losses to an acceptable level just enough to be able to drill ahead to section TD.

Rig and other third party equipment failure and repair were also major drivers in NPT on the last campaign. Each major contractor's performance were monitored and were required to have adequate back-up tools and equipment to mitigate downtime. Rig performance were reviewed weekly while other contractor's performance were reviewed on a per well basis.

Due to this careful surveillance and application of fit-for-purpose technologies, the 2020-2022 average NPT improved to 12% from 28% - the NPT of 12% was the previous campaign's best performance. The worst NPT for the 2020-2022 campaign is on well B-2, when the bit lost cones and the well needed to be sidetracked. On the other hand, the best performance for this campaign brought down NPT to a low 3%, which is also on our last and best well. The downward trend improvement in the NPT was the result of the end-of-well lookback and intense surveillance on the contractors' service quality.

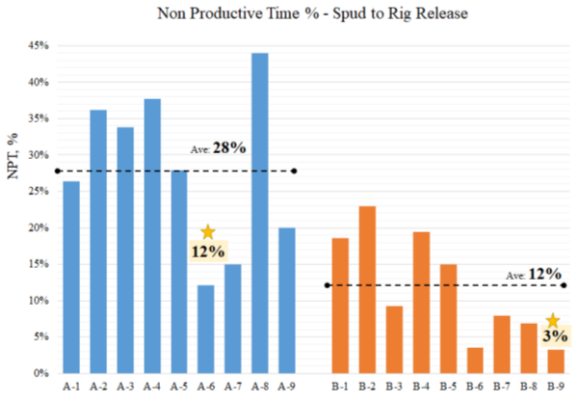

Figure 7 Significant NPT reduction was accomplished in the 2020-2022 drilling campaign

4. CONCLUSION

PGPC drilling wells in Mak-Ban after ~20 years presented a lot of challenges to the management, resource group, and drilling team. However, it also presented opportunities to set the tone in encouraging management to further invest in

drilling more wells by ensuring a good overall performance for this campaign.

The journey to this performance improvement starts with the formation of strong project team composed of interdisciplinary team members from the resource group, surface facilities, and of course, drilling team. By breaking the silo-style project execution, the project team is able to collaborate and infuse their technical expertise on their respective disciplines freely and better react in a timely manner when issues arise. Within the drilling team, individual subject matter experts (SMEs) were established and focused on improving their areas, giving technical support to the Lead Drilling Engineer per well on planning, execution, and performance reviews afterwards. With this revised set up, each well is every drilling engineer's well, which was a game-changer in improving involvement and accountability. Achieving the best ROP, lowest NPT, and fastest well drilled was the result of the whole team's contributions.

One of the best practices for this campaign is the detailed and interdisciplinary well reviews conducted every hole section and every end-of-well in order to capture the lessons learned and focus on the items that need improvement. These were very instrumental in the continued progress seen per well and in making sure that the rig and all contractors' equipment were in good condition, thereby eliminating NPTs from failures and repairs

Another innovative idea in terms of well design is the optimization of the double tieback section by incorporating a casing crossover and running a tandem dual size casing string. This eliminated one set of casing and cementing activity which can take 1-2 days easily.

One issue that was adequately addressed in this campaign was the stuckpipe issues resulting from hole cleaning. For this campaign, aerated drilling technology was used with parameters being calibrated and improved with the pressure-while-drilling (PWD) sensors that were added into the BHA. In addition to the air, mud properties were kept in check and small frequent sweeps were implemented.

The rig was able to optimize on bottom drilling time by checking PWD trends eliminating unnecessary wiper trips or extended circulation, conversely, it was also able to dictate when the latter were needed to avoid stuckpipe scenario.

In terms of addressing lost circulation which contributes long NPTs, the team was able to successfully eliminate cement plugs in the shallow section using air, and also cement areas with massive losses (ie reservoir section) using aggressive cement slurry design.

In summary, the remarkable improvement in the drilling performance was not achieved by chance as shown in the continued improvement with every well in ROP, depth, and %NPT. It was the product of systematized planning processes and close collaboration among well decision team, drilling operation, business partners, and all other involved stakeholders.

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