

First Implementation of Innovative Hybrid Drill Bit Technology Set Benchmark Performance in Indonesia Geothermal Well

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ABSTRACT

Indonesia, situated within the geologically active Ring of Fire, is the world's second-largest producer of geothermal energy, a testament to its significant geothermal potential. Streamlining the drilling process for geothermal wells can further bolster Indonesia's geothermal infrastructure, substantially contributing to global climate action in alignment with the sustainable development goals. This paper presents a case study demonstrating the successful integration of innovative hybrid polycrystalline diamond compact (PDC) and roller cone technology, which contributed significantly to reducing drilling days in a West Java geothermal well. This initiative accelerates renewable energy drilling goals and sets a precedent for sustainable development.

The challenging igneous lithology of the Darajat field in West Java necessitated innovative solutions. In a remarkable display of collaboration, the geothermal operator and service provider jointly designed and implemented drilling strategies featuring hybrid drill bit technology in the 17 ½-inch section of the well. This strategic approach not only enhanced drilling efficiency and overcame geological complexities but also ensured the economic viability and success of geothermal projects, underscoring the power of collaboration and innovation in our industry. By combining the cutting action capabilities of polycrystalline diamond compact (PDC) and roller cone technologies, the hybrid drill bits have proven to be a game-changer in drilling through challenging and interbedded volcanic formations, significantly boosting drilling performance.

The initial application of hybrid drill bit technology in the 17½-inch section contributed to a remarkable result in the Darajat field, setting new benchmarks for geothermal drilling performance. The hybrid bit contributed to a superior drilling performance by achieving an average rate of penetration (ROP) of 48.03 ft/hr in one run to target depth, marking a substantial 58% increase in ROP compared to the offset tricone bit. Afterwards, this hybrid bit was rerun to drill the next well and achieved an average ROP of 62.5 ft/hr in one run to target depth, a 106% increase of ROP compared to the offset tricone bit.

This successful deployment contributed to extended drilling intervals and significantly reduced drilling time, underscoring the transformative impact of hybrid drill bit technology in geothermal applications. This study sheds light on the collaborative efforts between operators and bit service providers, leading to pioneering advancements in geothermal drilling technology within the challenging igneous formations of the Darajat Field. Integrating hybrid drill bit technology is a testament to innovation and excellence within the geothermal society, offering valuable insights for engineers operating in similar demanding geothermal environments. By enhancing drilling efficiency and reliability, adopting hybrid drill bit technology presents a transformative contribution to advancing geothermal production capabilities.

1. INTRODUCTION

The Darajat geothermal field, located in West Java, Indonesia (see Figure 1), stands as the nation's largest vapor-dominated geothermal resource and is one of only two volcano-hosted vapor systems in the country (Hadi, 2001; Intani et al., 2020). Commercial operations began in 1994 with Unit 1 (55 MWe), followed by expansions in 2000 (Unit 2, 95 MWe) and 2007 (Unit 3, 110 MWe, later increased to 121 MWe), resulting in a total installed capacity of 271 MWe (Intani et al., 2020; Intani et al., 2021). Pre-production reservoir assessments indicate temperatures ranging from 225 to 245 °C and pressures around 35 bar, with non-condensable gas (NCG) content below 2 wt%, reflecting Darajat's favorable steam chemistry (Hadi, 2001; Intani et al., 2020).

Geologically, Darajat is part of the Kendang volcanic complex, a Quaternary multi-center volcanic region that includes the Papandayan and Guntur volcanoes. The geothermal reservoir is primarily hosted within the Andesite–Intrusive Complex, which consists of andesite lava flows and subordinate pyroclastic breccias, intruded by diorite to microdiorite dikes, sills, and small stocks (Hadi, 2001; Rejeki et al., 2010; Intani et al., 2021).

Within this framework, microdiorite serves as both a facilitator of permeability and a significant drilling challenge. As a dense, crystalline, and brittle intrusive rock, microdiorite often contains high-density minor fractures, contributing to durable open-fracture pathways in the reservoir (Intani et al., 2020; Rejeki et al., 2010). However, its high rock strength and abrasiveness (with UCS > 15 ksi) make drilling particularly demanding compared to hydrothermally altered tuff breccias and lapilli tuffs (Sari et al., 2025; Waluyono et al., 2024). In

these hard intervals, directional drilling faces increased torque, greater tool face instability, a higher risk of vibration and whirl, and accelerated wear on outer-row cutters and inserts if drilling parameters are not carefully managed (Rejeki et al., 2010; Intani et al., 2020).

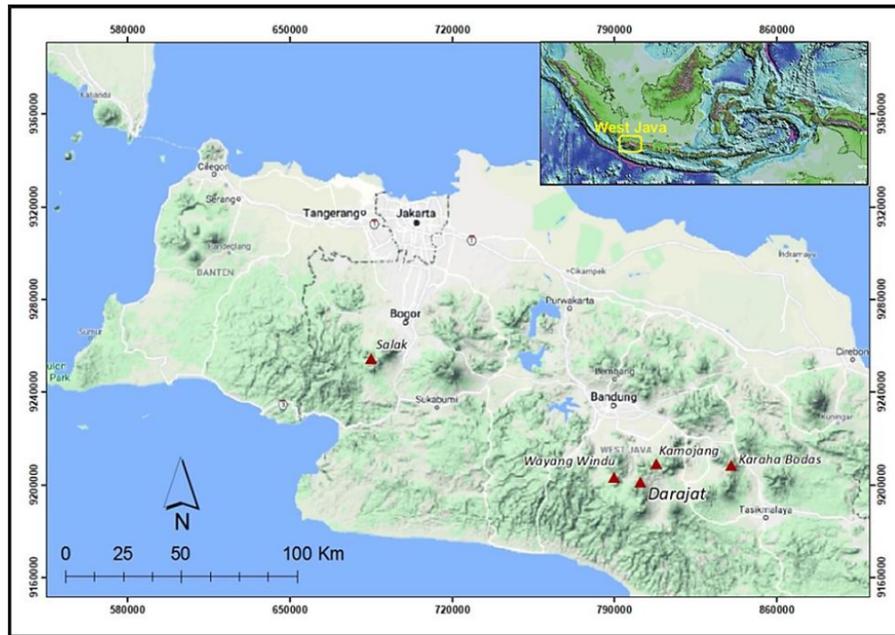


Figure 1. Location of the Darajat Geothermal Field in West Java, Indonesia (Intani, 2020)

An integrated evaluation of offset wells drilled by the operator was conducted, incorporating drill bit performance records, operational parameters, resistivity logs, dull bit imagery, subsurface drilling forecasts, and mud logging data. This analysis highlighted recurring limitations in drilling performance and overall efficiency. To address these issues, the operator aims to optimize drilling operations by minimizing non-productive time, total drilling duration, and associated well costs. Among the potential solutions identified, the deployment of hybrid drill bit technology represents a promising approach that has not previously been applied in this field.

2. DRILLING OVERVIEW AND CHALLENGES

The Darajat geothermal wells are designed to traverse complex volcanic stratigraphy while meeting demanding directional drilling requirements. As illustrated in Figure 2, the 17½-inch hole section typically spans 1,500 to 2,800 ft measured depth (MD) and represents the most technically challenging interval of the wellbore due to its lithological variability, mechanical properties, and extended length. In addition to these geological complexities, this section accommodates significant directional work, dogleg severity commonly ranges from 2° to 3° per 100 ft, with final inclination angles between 20° and 45°, making directional control critical for well trajectory integrity.

Table 1. Summary of 17 ½-inch Section Drilling Performance History

Depth Range (ft MD)	Dominant Lithology	Alteration Trend	Clay Content	Hardness	UCS (ksi)	Bit Performance Overview
~1,300 – 1,600	Tuff breccia / Coarse pyroclastic	Weak–moderate argillic	High (>20%)	Soft–Medium	~9	High ROP (50–80 ft/hr), minimal torque issues, risk of partial loss circulation
~1,600 – 2,200	Coarse pyroclastic (silicified)	Moderate–strong argillic → transition	Moderate	Medium hard	~10–12	ROP drops (40–60 ft/hr), torque increases, bit wear moderate
~2,200 – 2,900	Coarse pyroclastic & Andesite lava	Argillic–propylitic transition	Low (<20%)	Hard	~12–14	ROP slows (30–50 ft/hr), torque spikes
~2,900 – 3,300	Andesite lava (dominant)	Strong propylitic	Very low	Hard	~15–16	ROP very low (15–25 ft/hr), bit dulling fast, high torque
~3,300 – 3,640	Microdiorite (deep zone)	Strong propylitic	Very low	Hard	~18–20	ROP minimal (10–20 ft/hr), severe bit wear, risk of stuck pipe

The stratigraphy within this interval transitions from hydrothermally altered tuff breccia into dense andesite lava flows and microdiorite intrusions, often intersecting fault-related damage zones. These formations exhibit high unconfined compressive strength (UCS), ranging from approximately 9 ksi in tuff breccia to over 18 ksi in microdiorite, coupled with low clay content and strong propylitic alteration, which significantly increases drilling difficulty compared to softer volcanic units (Table 1).

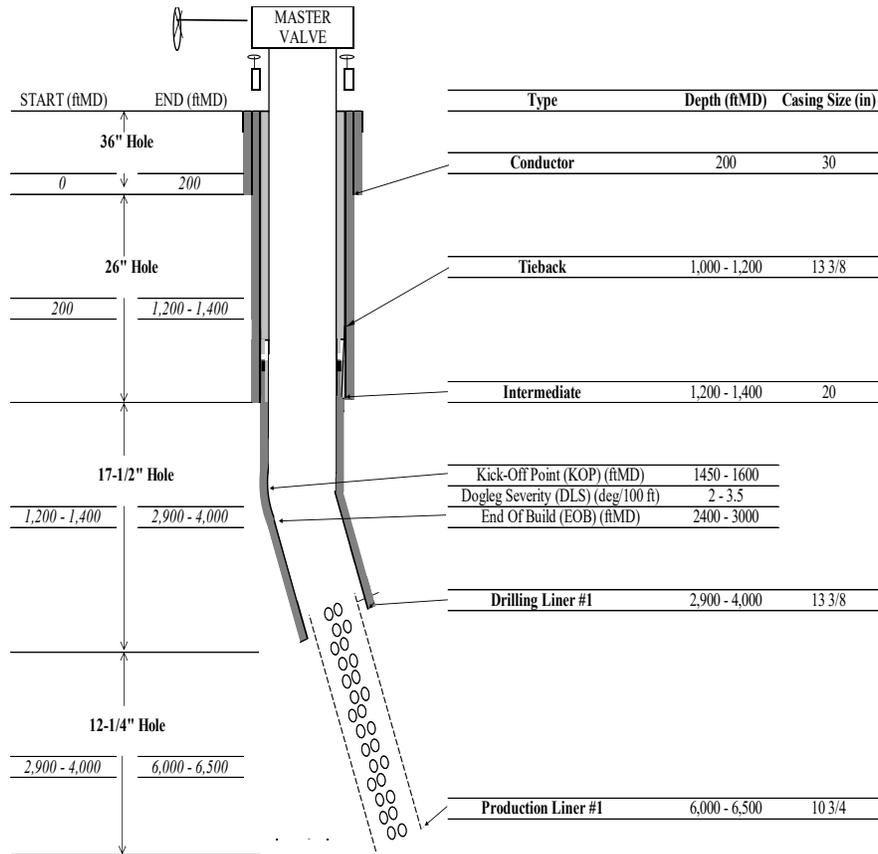


Figure 2. Typical Well Schematic

Historically, the 17½-inch section in the Darajat geothermal field has been drilled mainly with tungsten carbide insert (TCI) and polycrystalline diamond compact (PDC) bits, as summarized in Table 2, with performance generally characterized by moderate rates of penetration (ROP), limited footage per run, and a requirement for multiple trips to reach section total depth. These outcomes are largely driven by the complex volcanic stratigraphy, in which extremely high-strength and abrasive andesite and microdiorite formations rapidly degrade cutters and bearings—particularly at the outer rows—resulting in under-gauge bits, shortened bit life, and significantly reduced ROP. The mechanical resistance of these lithologies induces elevated torque, severe vibration, and tool face instability, complicating directional control and increasing the risk of bit and bottom-hole assembly (BHA) failure. Drilling efficiency is further compromised by frequent loss-circulation events that necessitate aerated or blind drilling, high formation temperatures that stress tool reliability, and rapid lithological transitions that can trigger motor stalls and vibration-related dulling.

Table 2. Summary of 17 ½-inch Section Drilling Performance History

Well Name	Pad	Bit Used	Footage Drilled	Total Bit Hours	Average ROP	Average Footage/Bit
Well-1	18	3	2588	120	21.63	863
Well-2	18	3	1906	96	19.88	635
Well-3	18	3	2358	172	13.75	786
Well-4	20	2	1930	148	13.06	965
Well-5	20	1	1849	122	15.14	1849
Well-6	18	2	2148	72	29.83	1074
Well-7	18	2	2135	78	27.46	1068
Well-8	18	2	1970	85	23.31	985

Well-9	15	2	2181	73	30.08	1091
Well-10	20	2	1832	123	14.89	916
Well-11	20	1	1928	58	33.05	1928
Well-12	20	1	1767	74	23.81	1767
Well-13	15	1	2437	51	48.03	2437
Well-14	18	1	1519	24	62.51	1519
Well-15	18	1	1395	24	58.86	1395
Well-16	20	1	2020	36	56.42	2020
Well-17	20	1	1800	28	63.83	1800

These operational challenges highlight the limitations of conventional bit technology in the Darajat field and underscore the necessity for innovative approaches—such as hybrid drill bits—to improve drilling efficiency, reduce operational risks, and achieve project objectives in Indonesia’s demanding geothermal environments.

3. HYBRID BIT TECHNOLOGY

The hybrid drill bit marks a significant technological advancement in geothermal drilling, integrating the cutting mechanisms of roller cone and polycrystalline diamond compact (PDC) bits into a single tool, as depicted in Figure 3. This dual-action design enables the bit to perform two complementary functions: the roller cones pre-crush hard and abrasive formations such as microdiorite and andesite—common in the Darajat field—thereby releasing formation stresses and shielding the PDC cutters from direct impact in the most challenging intervals. Simultaneously, the PDC cutters deliver aggressive shearing action, facilitating rapid penetration in softer or interbedded zones and maintaining high rates of penetration (ROP) even as lithological properties fluctuate.



Figure 3 Hybrid Bit

Beyond its cutting versatility, the hybrid bit features a reinforced shoulder with top-milled pockets and large radius to reduce stress and enhance durability. Advanced diamond cutters, optimized geometry, and strategic placement further improve efficiency, vibration control, and bit life. 3D bit-rock interaction modeling customizes the bit for Darajat’s specific geology and drilling parameters, ensuring reliable performance. Hybrid bits excel in tool-face control for directional drilling, especially in interlayered formations where conventional tungsten carbide insert (TCI) bits lack aggressiveness and PDC bits can cause excessive vibration and BHA instability. The hybrid bit’s design was selected after evaluating these challenges, ensuring suitability for the demanding geothermal environment.

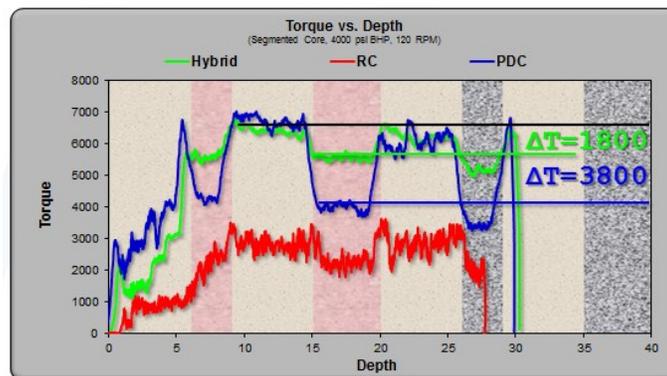


Figure 4 Torque Response in Segmented Core (Pessier & Damschen, 2011)

The features from the hybrid bits to ensure successfully first run in the challenging Darajat’s field is as follows:

- Sharp and Dense Cones: fast & durable generation of Hybrid bit with sharp and dense TCI produces several micro-fractures, proving to be the most effective in the hard interval allowing very high ROP in soft interval of geothermal formations.
- Optimized Cutter Layouts: optimization in cutter placement provide more improvement in cutting mechanism efficiency to help drill faster.
- Reinforced Cutter Technology: introduce a secondary chamfer on the diamond face of the cutter that enables a higher loading to be applied without breakage –offering significantly higher impact strength and improved wear resistance compared with traditional cutter geometry.
- Premium Carbide Grades: premium carbide grades were engineered to improve abrasion and toughness resistance to keep the compacts sharp.
- Engineered placement design on the shoulder/gauge area for improved durability with one row of 100% diamond gauge compacts in each roller cone.

Laboratory drilling tests provide empirical evidence for the superior performance of hybrid drill bits in heterogeneous formations, using segmented rock samples comprising Carthage Marble (15 ksi UCS), Jasper Quartzite (36 ksi UCS), and Gabbro (49 ksi UCS) under fixed weight-on-bit (WOB) and confining pressure conditions to compare torque and rate of penetration (ROP) responses of hybrid, roller-cone (RC), and polycrystalline diamond compact (PDC) bits. The RC bit consistently exhibited the lowest ROP across all lithologies, particularly in Gabbro, while the PDC bit achieved approximately twice the ROP of the RC bit in Carthage Marble but experienced a pronounced performance degradation in Jasper Quartzite, where its ROP was only marginally higher than that of the RC bit.

In contrast, the hybrid bit outperformed the PDC bit in Carthage Marble and sustained higher ROP in both Jasper Quartzite and Gabbro, nearly doubling the penetration rates of the PDC and RC bits (Pessier & Damschen, 2011). Figure 4 illustrates that the PDC bit exhibited torque fluctuations exceeding 60% during transitions between Jasper Quartzite and Carthage Marble, with similar instability in subsequent transitions, whereas the RC bit showed smoother torque behavior and the hybrid bit reduced torque variability by more than 50% relative to the PDC bit. These results demonstrate that the combined crushing–shearing mechanism of hybrid bits improves drilling efficiency in interbedded and hard-rock environments by mitigating vibration-induced dysfunctions; although their application is constrained by roller-cone bearing life, the associated reduction in mechanical specific energy (MSE) through enhanced ROP and vibration control can potentially extend operational performance, supporting laboratory conclusions that hybrid bits are particularly suitable for Indonesia’s geothermal formations.

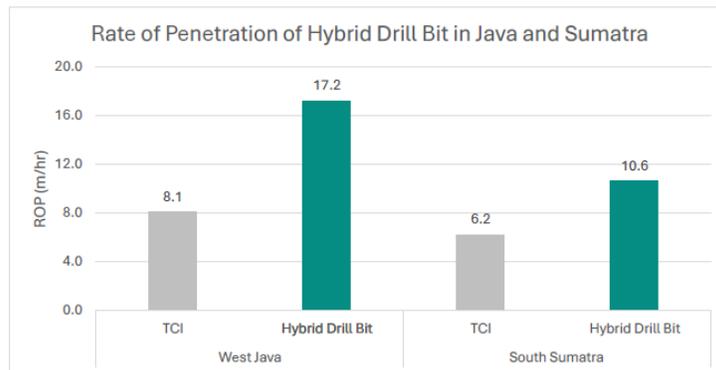


Figure 5 Rate of Penetration of Hybrid Drill Bit Compared to Offsets in West Java and South Sumatra (Purba et al, 2025)

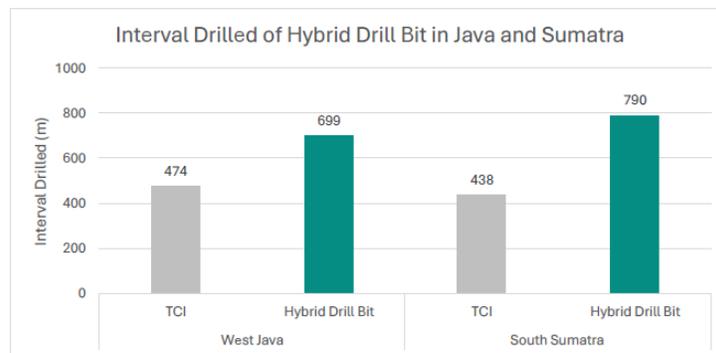


Figure 6 Average Interval drilled of Hybrid Drill Bit in West Java and South Sumatra (Purba et al. 2025)

Field data collection from West Java and South Sumatra area further support the hybrid bit’s superiority over TCI bits. As illustrated in Figures 5 and 6, hybrid bits achieved a 112% increase in ROP and a 47% longer average interval drilled in the 17.5-inch section. Unlike TCI bits, which often require multiple runs to reach total depth, hybrid bits consistently able to complete TD section in a single run, and in some cases, drilled two wells with one bit (Purba et al., 2025).

The optimal 17.5-inch hybrid bit design, as shown in Figure 6, was selected based on several criteria: proven performance in geothermal environments, a frame configuration featuring six blades and three cones with a strategic cutter layout (19-mm cutters in the nose for aggressiveness and ROP enhancement, 16-mm cutters in the shoulder for durability in abrasive formations), formation-specific cutter selection to balance ROP potential and wear resistance, cone design optimization for bearing life and carbide grade, and rigorous verification of total flow area, drilling parameter limits, and gauge specifications to ensure operational suitability.

The decision to implement the hybrid bit in the latest Darajat campaign is driven by its potential to address persistent challenges during drilling the 17.5-inch section—namely, rapid bit wear, high vibration, multiple trips and inconsistent tool-face control. The hybrid bit’s dual-action mechanism and advanced features were expected to deliver improved durability and gauge retention by distributing cutting loads and protecting critical components, higher and more consistent rates of penetration through efficient drilling across variable lithologies, reduced vibration and better directional control by stabilizing the tool-face, and fewer trips with lower overall drilling costs due to enhanced durability and performance. These anticipated benefits positioned the hybrid bit as a robust solution for improving drilling performance in Darajat’s demanding geological environment, with its implementation aiming to set a new benchmark for geothermal drilling efficiency.

4. METHODOLOGY

A systematic approach was employed to evaluate and optimize the performance of the hybrid drill bit. The process began with a comprehensive analysis of twelve offset wells, incorporating BHA configurations, mud properties, bit records, dull bit images, lithological data, and depth-based drilling parameters. This dataset enabled the identification of operational barriers and informed the development of a drilling roadmap tailored to maximize hybrid bit efficiency.

Formation data were acquired through logging and simulated using Baker Hughes’ UCS lithology estimation software. Key drilling parameters from offset wells, including those for TCI bits, along with formation characteristics, BHA setups, directional trajectories, and mud properties, were input into a proprietary 3D drilling simulation program (Figure 7). Simulation results indicated that, under equivalent WOB and RPM, the hybrid bit could achieve up to twice the ROP of conventional TCI bits. The WN number (product of WOB and RPM) was used to quantify applied power, with a maximum value of 9000 for the 17.5-inch hybrid bit.

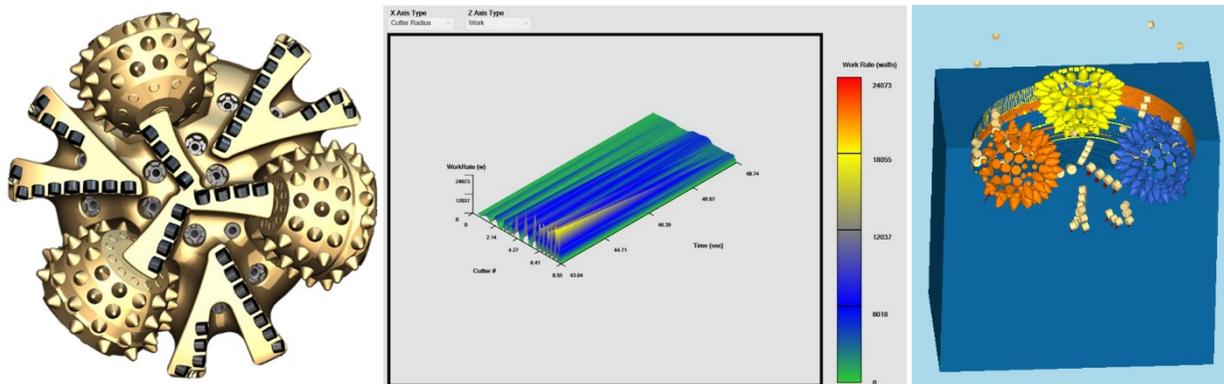


Figure 7 Hybrid drill bit in 3D Drilling Simulation Program

Further simulations were conducted to develop a drilling roadmap (Figure 8) that would optimize instantaneous ROP while maintaining bit integrity. The roadmap categorized operational ranges based on the WN number: the lower end (blue) indicated low ROP (<8 m/hr), optimum performance (green) corresponded to ROP >8 m/hr with good bit durability, the warning range (yellow) signaled parameters approaching operational limits, and the limit range (red) denoted conditions likely to overload the bit and compromise integrity. These categories were determined using finite element method simulations of bit stress levels. Additionally, the bit’s 80% reliability threshold—derived from statistical analysis of geothermal bit usage in Indonesia—was incorporated to minimize the risk of bearing failure by recommending that on-bottom revolutions remain below this threshold.

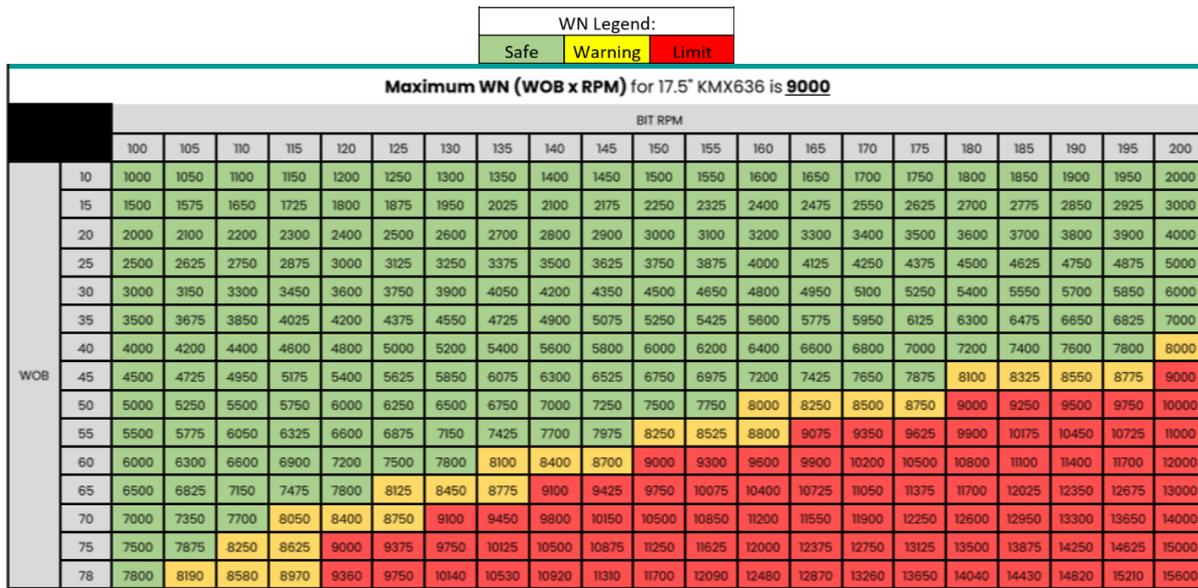


Figure 8 Drilling Roadmap of 17.5-in Hybrid drill bit for Well C

The study systematically compared the performance of the hybrid bit in the 17.5-inch section during the 2024 Darajat drilling campaign with the performance of conventional bits from offset wells on pads 15, 18, and 20, ensuring that improvements attributed to the hybrid bit were evaluated under equivalent operational conditions. The methodology encompassed data collection, metric selection, normalization, and comparative analysis. Drilling records for five wells (Well 13 to 17) where the hybrid bit was deployed were collected, including bit run sheets, daily drilling reports, and IADC dull grading logs. Historical data from offset wells using TCI and PDC bits provided baseline metrics for comparison.

To ensure data quality, all datasets underwent cross-checking for completeness and consistency, with runs involving incomplete data, sidetracks, or short clean-out intervals excluded from analysis. The key performance indicators (KPIs) selected for evaluation included interval drilled per run (ft), average ROP (ft/hr), number of trips per section, and dull grading/gauge retention. Statistical analysis was performed to calculate average values, ranges, and standard deviations for each KPI, with outliers excluded to prevent skewed results. Graphical representations—such as boxplots, bar charts, and summary tables—were generated to visualize differences in ROP, interval per run, and trip counts across campaigns. Only primary drilling runs were included, and the analysis focused exclusively on the 17.5-inch section to ensure direct comparability.

5. RESULTS

The implementation of the hybrid bit in the 17.5-inch section, illustrated in Figure 7, during the last Darajat drilling campaign, has resulted in significant improvements across all key performance indicators (KPIs) compared to conventional TCI and PDC bits, as summarized in Table 3 and Figure 8.

Table 3. 17 1/2-inch Section 2024 Darajat Drilling Campaign Performance Summary

Well Name	Type	Footage Drilled (ft)	Avg ROP (ft/hr)	Bit Dull Grade	Avg RPM (rpm)	WOB Avg (1000 lbf)
Well-13	Hybrid Bit	2,437	34.41	1-2-WT-A-E-I-CT-TD	136.52	41.29
Well-14	Hybrid Bit (RR*)	1,519	34.25	2-3-WT-A-F1-1/8-BT-TD	125.93	50.15
Well-15	Hybrid Bit	1,395	39.69	1-1-WT-A-E-IN-CT-TD	120.97	32.20
Well-16	Hybrid Bit	2,074	42.45	2-8-BT-G-F1-5/16-CT-TD	146.80	43.35
Well-17	Hybrid Bit	1,800	65.22	1-2-WT-A-E-1/16-CT-TD	171.22	47.53

*RR: Re-run bit from previous well

The average interval drilled per run increased markedly with the hybrid bit, rising from a historical average of 1,160 ft with conventional bits to 1,830 ft with the hybrid bit. This represents an improvement of more than 50%, enabling longer drilling intervals before bit replacement and contributing to greater operational efficiency.

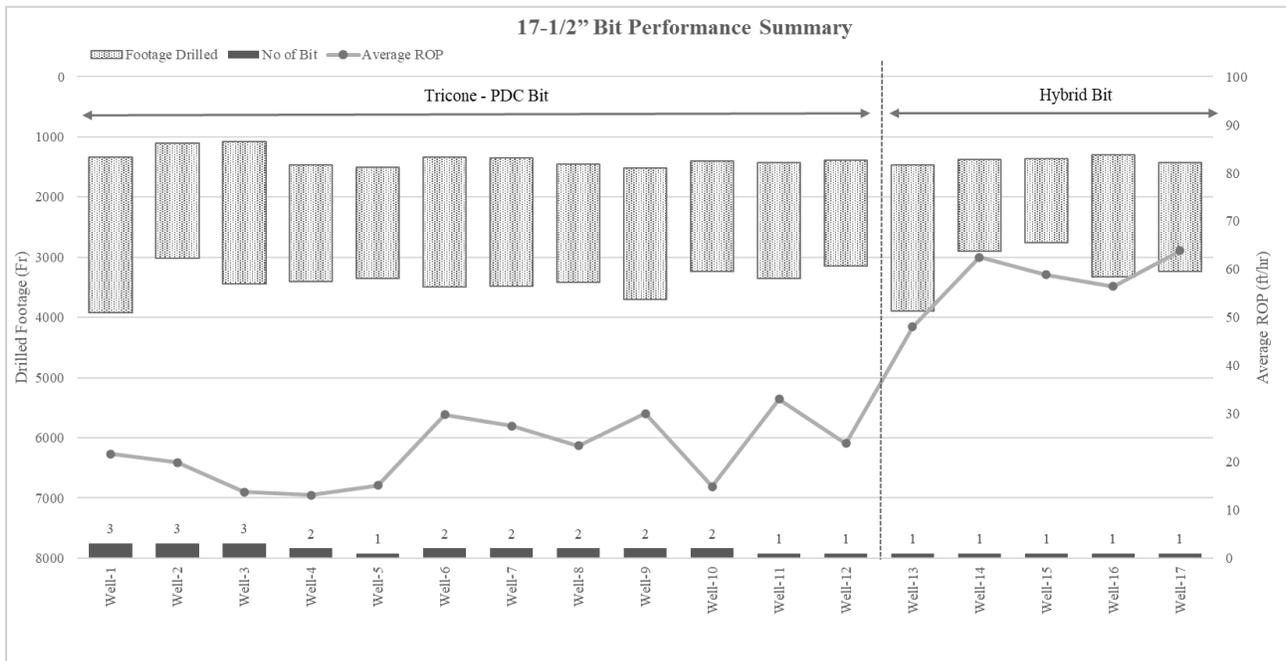


Figure 9 The Comparative Performance in Terms of ROP, Interval per Run, and Trip Count

The hybrid bit achieved a substantial increase in drilling speed. The average ROP improved from 22 ft/hr with conventional bits to 60 ft/hr with the hybrid bit—almost a threefold increase. This enhanced ROP is clearly depicted in Figure 8, which compares ROP performance across wells.

In addition, as illustrated in Figure 9, operational efficiency was further demonstrated by a reduction in the number of bit trips required to complete the 17.5-inch section. With the hybrid bit, each well section was consistently drilled to casing point in a single run, whereas conventional bits often required multiple trips. This reduction in trips directly minimized non-productive time and associated risks of hole exposure time.

Bit durability and wear resistance were also significantly improved. The hybrid bit consistently exhibited minimal wear, as indicated by favorable dull grading and gauge retention (see Table 3 and Figure 10). The bit maintained effective bearing condition, with only a quarter of the 80% reliability threshold utilized, and remained in gauge after drilling, in contrast to TCI bits, which frequently experienced bearing failures and under-gauge conditions.



Figure 10 Hybrid drill bit On surface condition after drilling wells 13

The enhanced drilling performance of the hybrid bit was achieved through collaborative, real-time optimization of drilling parameters. The overall parameters applied on the 17.5-in hybrid drill bit in offset well are operated within the WN recommendation range as shown in roadmap in Figure 8. The hybrid drill bit with drilling roadmap has demonstrated a good correlation to bit performance (ROP) while maintaining the bit integrity.

Tables 3 summarizes the operational ranges and average parameters applied, while Figure 11 presents the depth-based drilling parameter profile for the hybrid bit run in Well 13 as the example. The WN range in this plot corresponds to the color-coded categories established in the drilling roadmap (Figure 8). Real-time parameter adjustments were coordinated between field personnel and the drilling team, with the primary goal of maintaining operations within the optimal range defined by the roadmap while meeting the objective of directional

control and drilling rate. The 17.5-inch section included multiple sliding intervals, during which bit inclination increased from 0° to 45°, necessitating lower RPM and resulting in WN values at the lower end of the recommended range.

The MSE plot in Figure 11 demonstrates ongoing optimization efforts to minimize mechanical specific energy and ensure efficient drilling. During drilling through Andesite Lava and Microdiorite formations, a decrease in ROP was observed. In response, WOB was incrementally increased while remaining within the recommended WN range, maintaining the target ROP—set at twice the offset average for tricone bits. Enhanced ROP also required diligent hole cleaning practices. The collaborative efforts established during the preparation phase, including the development of the drilling roadmap, along with the execution phase involving real-time drilling parameter optimization, have culminated in benchmark drilling performance for the hybrid drill bit.

In summary, the combination of a well-developed drilling roadmap and real-time parameter optimization led to benchmark drilling performance for the hybrid bit, underscoring the value of collaborative planning and execution in challenging geothermal environments.

- ROP performances are higher compared to offset wells with an optimized drilling parameter based on drilling roadmap applied, 17% lower average WOB was applied on hybrid drill bits while maintaining 184% ROP response compared to TCI in offset well. The hybrid drill bit ROP performance could be improved further with an increased WOB, similar to TCI bits.
- Improving bit dull grade by maintaining parameters and applied consistent MSE for bit lifetime.

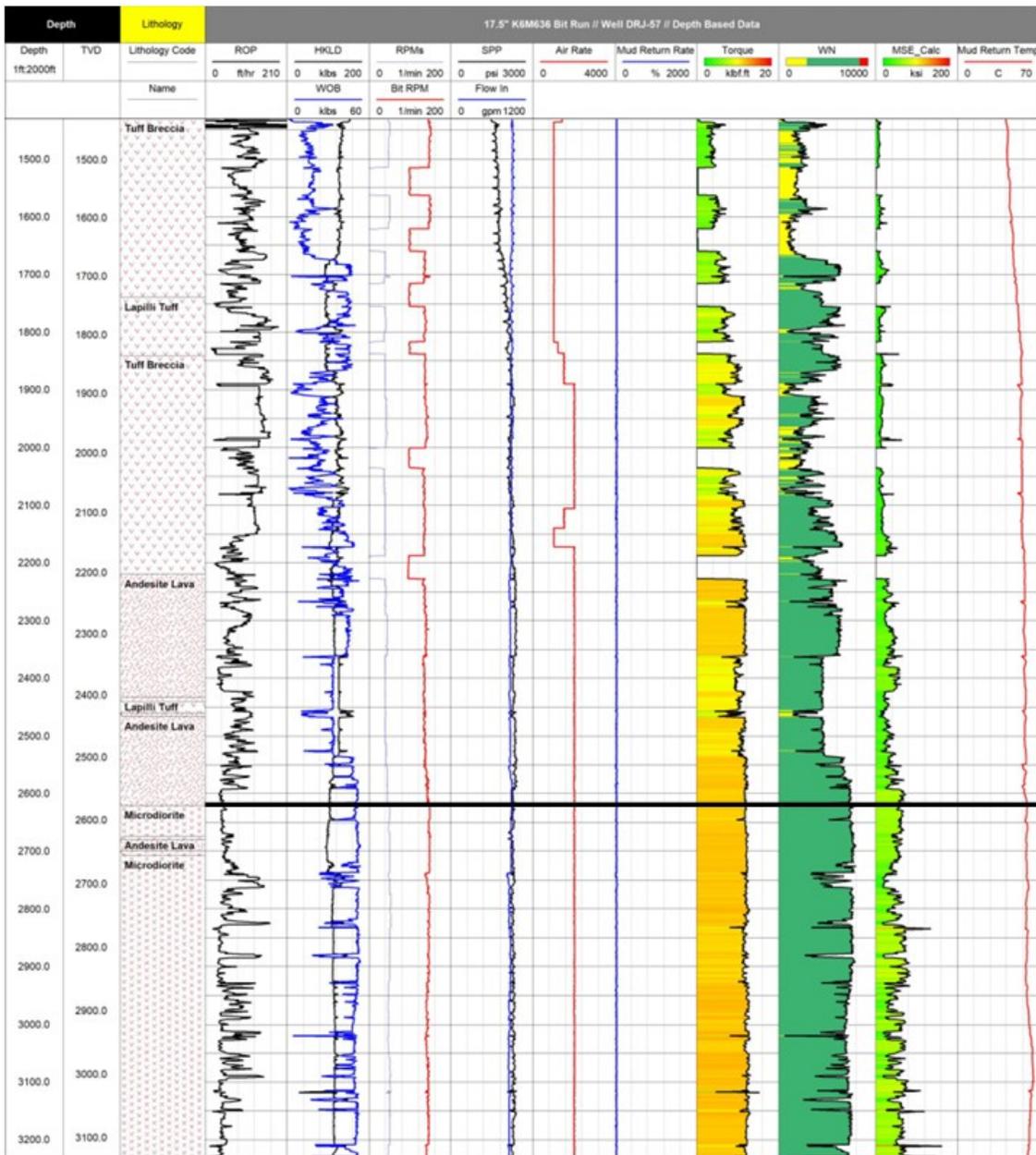


Figure 11 Depth based drilling Parameters response in Well 13

6. DISCUSSION

As described on this paper, the last Darajat drilling campaign demonstrated that the hybrid bit delivered substantial improvements in the 17.5-inch section compared to conventional TCI and PDC bits. The hybrid bit's dual-action mechanism—combining roller cone crushing and PDC shearing—enabled efficient drilling across the highly variable and abrasive lithology of the Darajat field. Reinforced shoulder design, advanced cutter technology, and 3D bit-rock interaction modeling further enhanced bit durability and performance. Field results showed reduced vibration and improved toolface control, which translated into longer intervals per run, higher ROP, and fewer trips.

Operationally, the hybrid bit's durability and efficiency led to a significant reduction in the number of trips required to complete the 17.5-inch section. Most wells were drilled to section total depth in a single run, minimizing non-productive time and lowering the risk of operational incidents associated with tripping. The improved ROP and reduced bit consumption contributed to shorter drilling times and lower overall well costs. The average drilling days for the 17.5-inch section per well were reduced, as shown in Figure 12, due to the increased ROP and interval drilled per run. Although the hybrid bit is comparatively more expensive, the substantial reduction in operating daily rate and bit consumption resulted in significant cost savings.

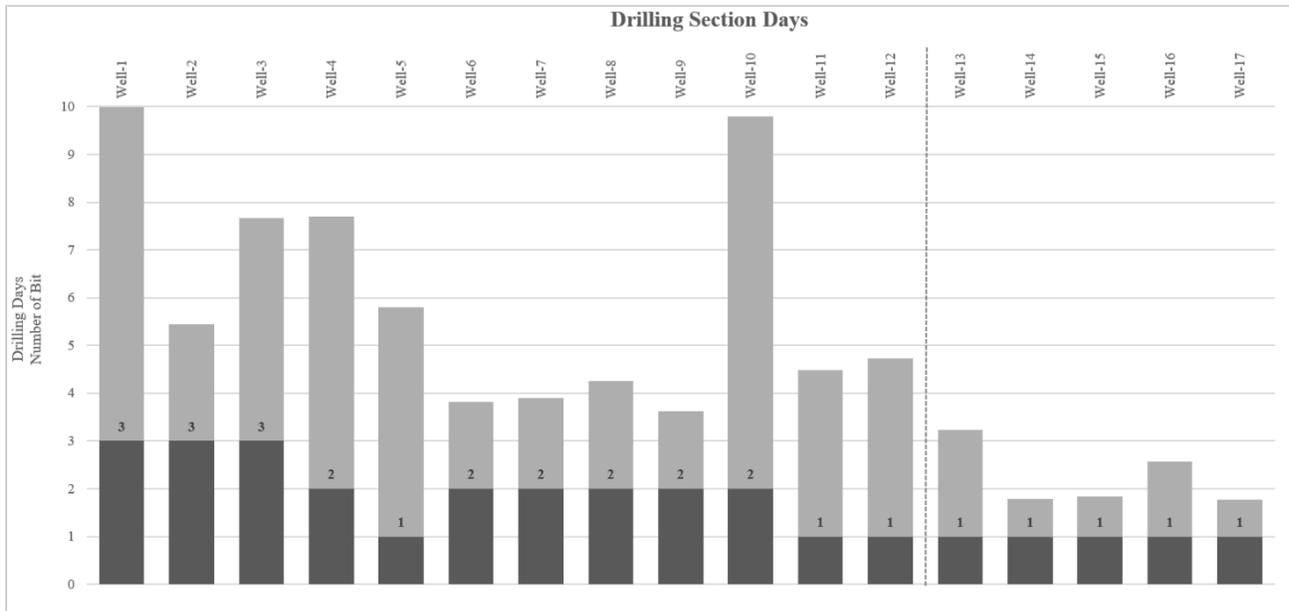


Figure 12 The Comparative Performance in Terms of Drilling Section Days

The successful implementation of the hybrid bit in Darajat highlights several best practices for geothermal drilling in challenging lithologies. These include careful bit selection and design customization based on offset well analysis and formation properties, continuous monitoring and optimization of drilling parameters to maximize ROP and minimize vibration, and regular dull grading and gauge checks to assess bit condition and inform future bit runs.

While the results are promising, it is important to note that lithological variability and operational differences between wells may influence performance outcomes. Further studies with larger datasets and additional wells are recommended to validate and refine these findings.

7. CONCLUSIONS

Darajat drilling campaign demonstrated that the hybrid bit is a robust and efficient solution for geothermal drilling in challenging lithologies. Compared to conventional TCI and PDC bits, the hybrid bit delivered substantial improvements in all key performance indicators, including longer intervals drilled per run, higher average rates of penetration, fewer trips per section, and superior bit condition that enable the bit to be run multiple times.

These advancements were driven by the hybrid bit's dual-action cutting mechanism, reinforced design features, and the application of advanced modeling and real-time parameter optimization. Operational benefits included reduced drilling time, lower overall well costs, and enhanced reliability, despite the higher initial cost of the hybrid bit.

The campaign also highlighted best practices for geothermal drilling, such as careful bit selection, continuous monitoring and optimization of drilling parameters, and regular assessment of bit condition. While the results are promising, further studies with expanded datasets and additional wells are recommended to validate and optimize bit selection and drilling practices for future campaigns.

In summary, the hybrid bit set a new benchmark for drilling performance in the Darajat field and offers valuable insights for geothermal operations in similarly demanding environments.

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