DINAME 2023 - Proceedings of the XIX International Symposium on Dynamic Problems of Mechanics,
A.S. De Paula, A.T. Fabro and M.R. Machado (Editors), ABCM.
Pirenópolis, Go, Brazil, February 26th to March 3rd, 2023

A model-based design approach to support a digital workflow to optimize drilling performance in Brazilian pre-salt carbonates

Romulo R. Aguiar

SLB. Av. Republica do Chile, 330 - 18o andar, Torre Oeste – Ventura Building, 20031-170. Rio de Janeiro, RJ Brazil

After 10 years of Brazilian presalt exploration and development, the carbonate reservoirs continue to pose drilling challenges, leading to unwanted bottomhole assembly (BHA) trips due to severe shock and vibration, low rates of penetration (ROP), and premature drill-bit cutting structure damage. Today, industry efforts to improve the performance in the Brazilian presalt carbonates are driven by trial and error, which is very costly in the ultradeepwater drilling environment. The adoption of a collaborative mindset since 2012 between a service provider and operator with the desire to bring about a step change in drilling efficiency on the Brazilian presalt cluster enabled a systematic learning framework to capture, evaluate, and reuse knowledge from drilling dynamics, geological, and petrophysical aspects. The innovation of this work is the implementation of an improved, fully digital bit design workflow, integrating calibrated 4D dynamic simulation model and petrotechnical expertise from drilling engineering, geomechanics, geology, and petrophysics groups to continue to push the drilling performance envelope in the challenging Brazilian presalt application.

Keywords: oilwell drilling, drilling dynamics, drill bit design, drilling performance

INTRODUCTION

The presalt reserves offshore Brazil currently drilled with various types of drill bits have proven to be a challenging environment. Consisting mainly of centimetric to metric cycles of laminites-spherulites-shrubs from an alkaline shallow-lake setting (Wright and Barnett 2015), such a heterogeneous formation can produce high-lateral vibration and stick/slip levels in the drilling system, leading to drill-bit cutter damage, bottom-hole assembly (BHA) tool failure, well deviation, low rate of penetration (ROP), nonproductive time, and increased drilling costs. Generally, in the reservoir intervals, operators encounter ring-out (RO) dull characteristics on the shoulder of the bit or core-out on the cone area, usually related to drilling dynamics. A huge challenge today is to reach the section total depth in a complex presalt interval during a single run with good overall ROP. Historically, polycrystalline diamond compact (PDC) bits have not performed well in hard and abrasion-prone applications within heterogeneous formations. With continuing advances in cutter technology and improved bit stability, these bits have increased their marketshare worldwide. Therefore, it is essential for the industry to create a differentiating cutting action to increase penetration rates and extend bit life to further reduce drilling costs.

The variability of performances for the same drilling system remains high in the reservoir section, and this is primarily linked to the heterogeneity and nonuniform nature of these carbonates, incremented by occurrences of silicates and volcanics. While some layers are homogeneous with low variance of rock properties, others are highly heterogeneous and laminated. The optimal drilling parameters for one layer might not be appropriate for another and could even be destructive for the drill bit and the entire drilling system, not to mention that worn or broken inserts present variations in the overall bit behavior. A good characterization and understanding of each of these zones, in addition to their occurrence and possible thickness, would be beneficial for drilling optimization.

Thus far, industry efforts to improve the drilling performance in the Brazilian presalt carbonates have been driven by a costly trial and error approach in the ultradeepwater drilling environment. Innovative solutions have shown to be a key game changer in the Búzios field, located in the presalt of the Santos basin. The challenges are enormous for this asset, considered to be the largest deepwater oil discovery in the world with estimated reserves of 10-B barrels of oil and gas (two-thirds of current proven reserves in Brazil). Located approximately180 km off the Brazilian coast with the reservoir more than 5000-m deep (underground), the field currently has four stationary production units operating at about 2000 m of water depth. With excellent quality reservoirs to 480-m thick and 60 drilled wells, Búzios contains the largest volume of oil and gas in deep waters in the world. With a total daily production of 687,000 BOE consisting of 551,800 BOPD and 21.5 million m3/D, according to the June 2021 ANP (Brazilian National Petroleum Agency) bulletin. The Búzios field is an undeniable example of the enormous potential of the assets in the Brazilian presalt (Fig. 1).

Figure 1 – Búzios field location (extracted from Internet websites google.com and petrobras.com.br).

The technology enablers that have continued to improve the drilling system efficiency are:

- In-depth understanding of the underlying root causes for low drilling efficiency using the stratigraphic zonation for drillability approach.
- In-house 4D dynamic drilling simulator provided by a service company with an application-specific virtual carbonate formation, capable of reproducing actual drilling conditions in the reservoir section.

Stratigraphic Zonation for Drillability Approach

The purpose of the stratigraphic zonation for drillability is to improve the benchmark and comprehend the performances of any given drilling system through each zone and direct the design of new engineering solutions. The stratigraphic zonation workflow consists of a five-step plan based on a rock typing approach. Fig. 2 shows that the process is not sequential and various loops are often required to converge toward the correct zonation.

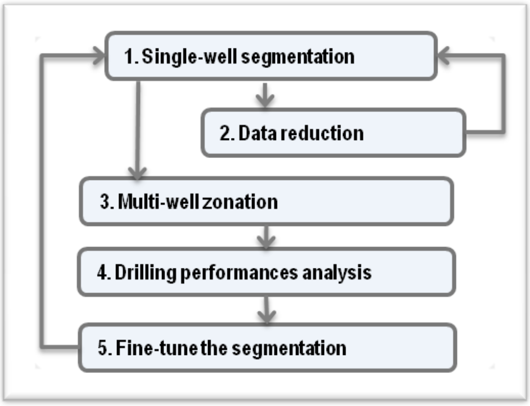

Figure 2 – Drilling zonation workflow (Hbaieb et al 2012).

The stratigraphic zonation for drillability methodology is not specific to the Brazilian presalt and can be applied to different fields. This methodology consists of a comprehensive workflow to facilitate integrating large volumes of multiwell data. These data can be acquired from drilling, logging, and coring operations, and be used to derive relevant drilling information and knowledge. Stratigraphic zonation is the process of defining groups of rocks with similar drillability characteristics. Similar approaches to this process have been applied in other fields of the petroleum industry, including rock typing and well log clustering, generally for reservoir identification and characterization (Hbaieb et al 2012). For the present work, two formations are considered with similar drillability if they exhibit similar performances in terms of ROP, vibration signature, and bit grading when drilled with similar drilling systems and operating parameters (Aguiar et al. 2016).

There are two challenges when attempting to identify facies between the zones for drillability compared with other applications. These challenges include decorrelating the formation intrinsic properties under in-situ conditions and confinements from the inefficiency induced by the drilling system with its continuously varying dynamics and bit wear. An attempt to identify the basis for drillability facies, e.g., mechanical specific energy, is not possible unless the bit wear and cutter conditions are quantified and known vs. depth. This information is not yet available using the current state of the art technology.

The data analysis was performed following a systematic workflow termed stratigraphic zonation for drillability (Hbaieb et al. 2012). Drilling, logging, and coring data were collected, and performance limiters were better identified. Field data analysis showed three distinct challenges that the drilling system faces during presalt carbonate drilling (Aguiar et al. 2016; Aguiar et al. 2019). These challenges included the following:

- Silicate nodule and layers—Nodules and layers have the effect of impact load on PDC cutters when switching from a soft to hard formation. This condition can lead to an abrupt loss of drilling efficiency due to PDC frontal impact damage that causes undesirable bit trips.
- Increased rock strength in low-porosity carbonate layers—Low-porosity carbonate layers (typically less than 5%) cause high-confined compressive strength under in-situ conditions. This condition is associated with PDC cutter wear and results in near zero ROP.
- Centimeter-scale rock heterogeneity—If dealing with various large-scale layers and stratigraphic zones when drilling the presalt was not complicated enough, some of these layers are found to be extremely laminated. Scratch testing of core samples (see Fig. 3) have shown a high heterogeneity at the centimeter scale caused by the changes in lithologies (calcilutite, dolomite, silicate, etc.) and porosities. Such heterogeneity can strongly impact the bit, BHA, and severe drillstring dynamics.

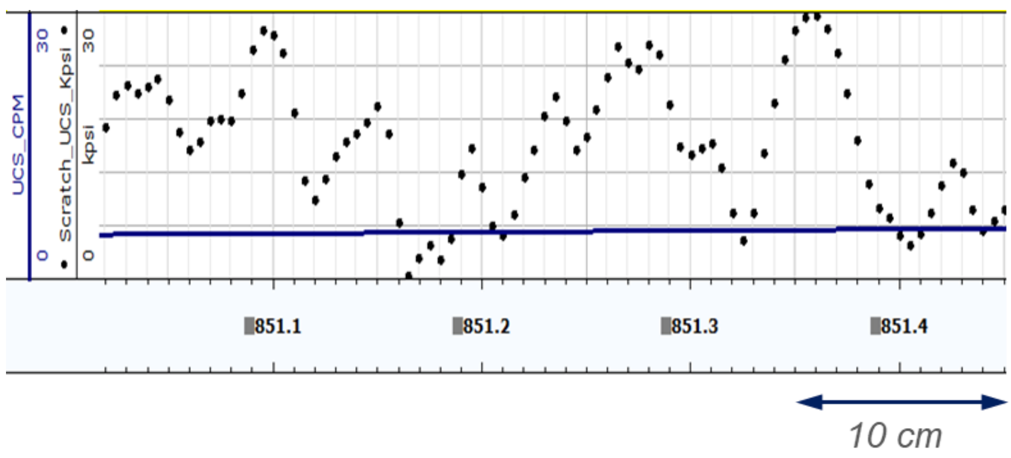

Figure 3: Heterogeneity from scratch testing, centimeter scale (extracted from Aguiar et al, 2016).

Advanced 4D Dynamic Drilling Simulation Software and the Virtual pre-Presalt Rock.

To avoid a trial-and-error approach in the present effort presented in this paper, especially in the expensive Brazilian ultradeepwater presalt environment, it is important to have a dynamic modeling system platform. This platform should have the objective to identify solutions that improve drilling performance by minimizing drillstring vibrations, optimizing drilling systems, and recommending best drilling practices for a given environment.

An advanced 4D transient drillstring dynamics modeling package was used to design the drill-bit cutting structure, predict the drilling dynamics of the bit, and plan the BHA and drilling parameters. In this package, cutting structure rock interaction is captured through laboratory testing. Formation samples of various types were gathered and analyzed at a drilling laboratory in Houston, Texas (Aslaksen et al. 2006). Indentation and scraping tests were conducted under confining pressure to obtain accurate cutter rock response in conditions similar to downhole conditions. Rock files were then generated for each rock sample, which contained the testing results at various backrake angles, siderake angles, and bevel sizes.

This transient drillstring dynamics package requires the following input: rock properties, cutting structure design details, BHA components, formation characteristics (heterogeneous, anisotropy, and orientation), well trajectory, casing schematic, and borehole geometry (Compton et al. 2010; Aslaksen et al. 2006). The drillstring dynamics package can be used to model and evaluate drillstring stability, steerability, efficiency, and wellbore quality. In fact, the model has many applications, such as bit design and selection, BHA design, drilling parameters optimization, and post-run validation and analysis based on field data.

Coupled with the detailed cutting structure model of the bit, the transient dynamics analysis is able to accurately capture the excitation forces at the cutting elements and evaluate their influence on the drillstring dynamic response. Compared with other transient analysis types, transient analysis containing the cutting structure generates a high-fidelity model. This model yields the most accurate drillstring mechanics prediction available, in spite of the cost of computation time (Wang et al. 2014).

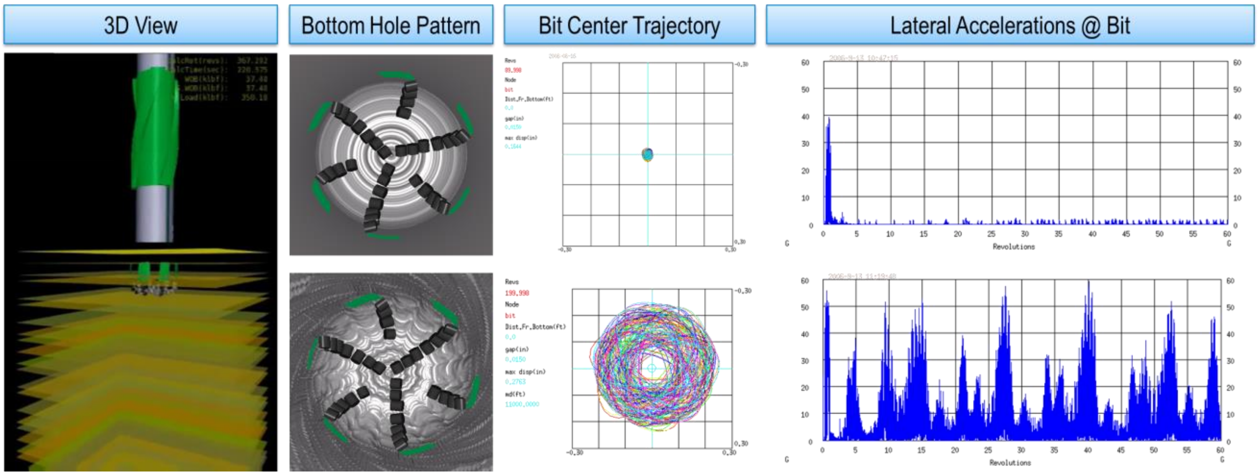

Figure 4: Snapshots of 4D drilling simulator. Comparison of how different drilling parameters (weight-on-bit and RPM) impact drill bit dynamics.

In previous work (Aguiar et al. 2019), a workflow was developed for a systematic drilling system optimization. The workflow consists of four steps. The main purpose of the workflow is to calibrate and validate the 4D drilling simulator software, using not only drilling data but also mud logging and wireline data through the stratigraphic zonation for drilling (Hbaieb et al. 2012). As a result, a virtual carbonate formation was created in the present effort to better reproduce the actual drilling conditions in the presalt carbonates. Fig. 5 shows the drilling zones in the virtual environment for drilling dynamics simulations. Examining the formation data allowed for identifying that the heterogeneity of the carbonates led to inconsistent unconfined compressive strength values. These peculiarities cause the impact and, consequently, the cutting structure damage, confirmed by the dull condition of the bits typically run in this field. With such an effort, it was possible to reproduce actual drilling conditions, including bit cutter forces and cutting structure degradation, and accelerate the learning curve in the exploratory campaign.

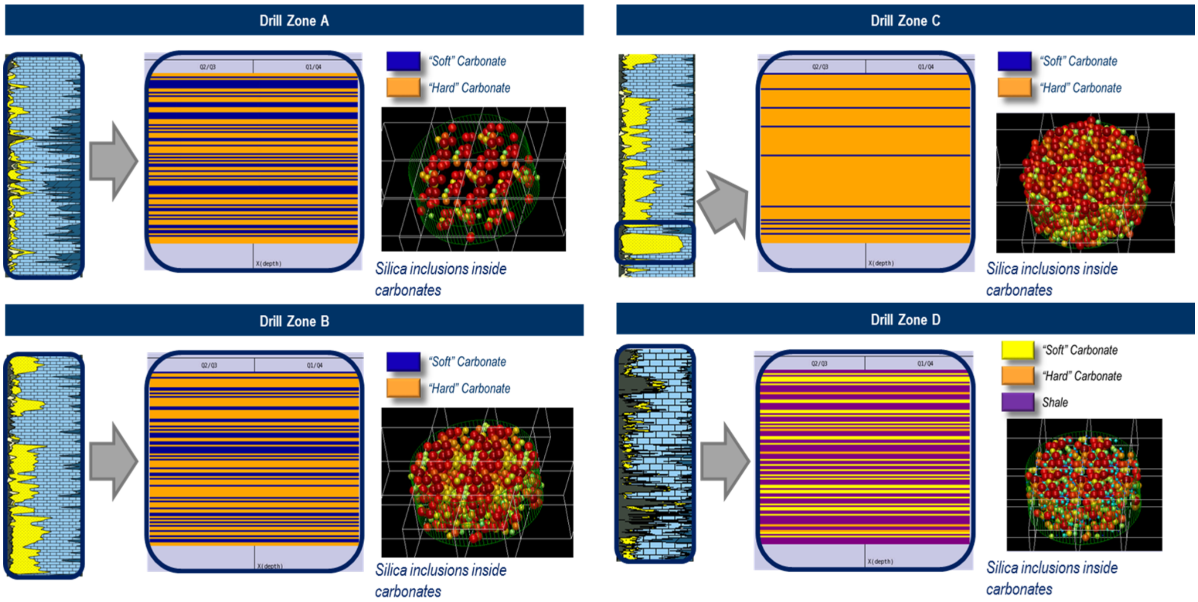

Fig. 5 — Stratigraphic zonation applied in the Búzios field. Drill zones are shown with partial representation using spectroscopy data and equivalent virtual rock inside in the 4D dynamic drilling simulation software presentation.

PROJECT DEVELOPMENTS

As part of the Búzios field exploratory and development campaigns in the Santos basin offshore Brazil, the operator's objective was to minimize drilling costs by eliminating unplanned trips into the wells. Accordingly, development of application-specific bit designs was required to optimize drilling efficiency in the wells with the goal of drilling the entire reservoir section in a single bit run. These specific bit designs were planned to challenge the various carbonate complexities within the field.

Project developments were divided in two parts as follows:

1. For the 12 ¼-in. borehole section, the bit design development followed an innovative full-digital cycle. After completing the stratigraphic zonation, calibrated 4D drilling dynamics software was used to identify the virtual presalt carbonate rocks in the Buzios field. As a result, it was possible to perform a full drill-bit design cycle in the new digital workflow.

2. For the 8 ½-in. borehole section, there was insufficient time to perform the full digital development as was performed for the 12 ¼-in. section. Instead, a more standard bit selection process took place. Due to the technology enablers, especially the presalt virtual rock and the 4D drilling dynamics simulation software, it was possible to select a bit from a current catalog of best fit-for-purpose drill bits for the application.

Fully Digital 12 ¼-in. Bit Design Workflow.

Commonly used for drill-bit selection, BHA optimization, and drilling parameters recommendations, the 4D simulation software was used in an innovative way for developing a new 12 ¼-in. bit design. Based on a calibrated model, supported by drilling data, wireline, and mud logging (Aguiar et al. 2019), all design interactions were tested inside of the 4D simulation software, simulating field conditions (rock formation, BHA, borehole, right heave, etc.). For such an accomplishment, a multidisciplinary approach was used. This effort made use of the service provider's bit designer, bits product engineer, a geologist, a petrophysicist, a modeling and simulation engineer, and the operator's engineering team. All of the simulation results were compared with the current drill bits being used in the Buzios field (Fig. 6). The goal of this effort was to have the next bit design provide a step change in drilling performance.

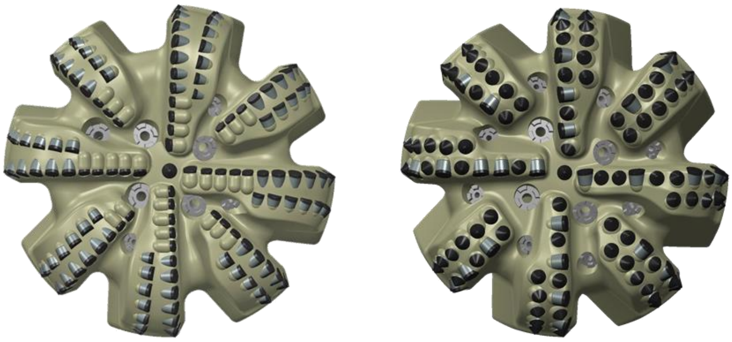

Figure 6 – Benchmark 12 ¼ in bits used in Búzios field before the new design development

The design process was divided into different levels with the purpose of evaluating, in a virtual environment, the various drill-bit design features (Fig. 7). The different levels included the following:

1. First round—Evaluate different drill-bit cutting structure layouts and compare them with the benchmark MSiZ813/ Z816 bit.

2. Second round—Use the updated cutting structure design and evaluate different gauge pad lengths and configurations (taper and helix angle).

3. Third round—Evaluate blade top configuration (depth-of-cut limiters).

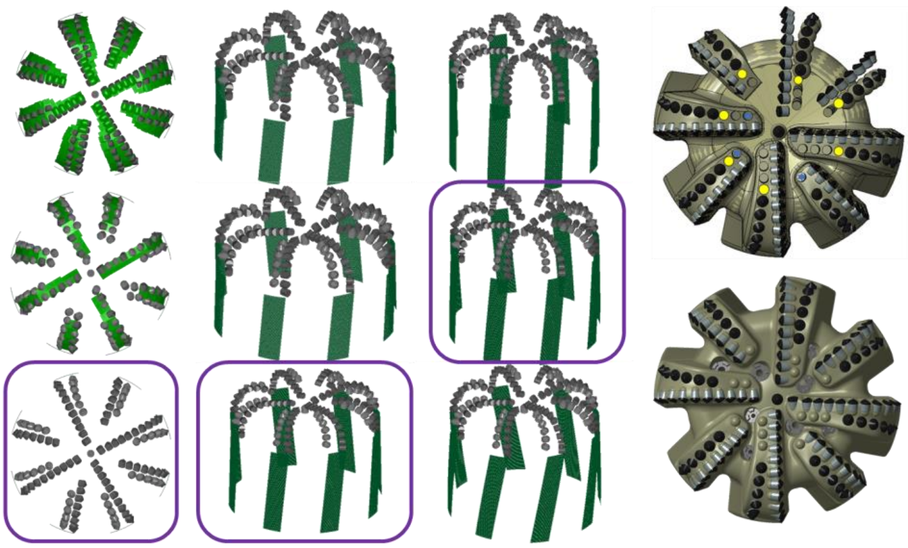

Fig. 7—Design process of drill-bit features in a virtual environment

During the design process, more than nine bit designs were simulated and evaluated. The capability of simulating such bit designs in a virtual environment, reproduces field condition, enables a deeper understanding of the important bit design features that have the most impact on the field performance. Also, using the 4D simulation software to evaluate, filter, and perfect bit designs results in substantial cost, manufacturing, and logistics benefits. These benefits are a result of eliminating the use of the trial-and-error approach in expensive and remote ultradeepwater locations, such as the Búzios field.

The new application-specific heavy-set bit design was developed incorporating years of lessons learned. The latest 3D cutter technology and valuable cutter-rock interaction knowledge derived from virtual carbonate formations was used to optimize cutting structure toughness and aggressiveness. Strategic design modifications were implemented to the baseline drill bit. During the design process, the best bit design candidate generated less bit torque, less surface torque, higher ROP, and lower vibration levels compared with the benchmark bits (Fig. 8).

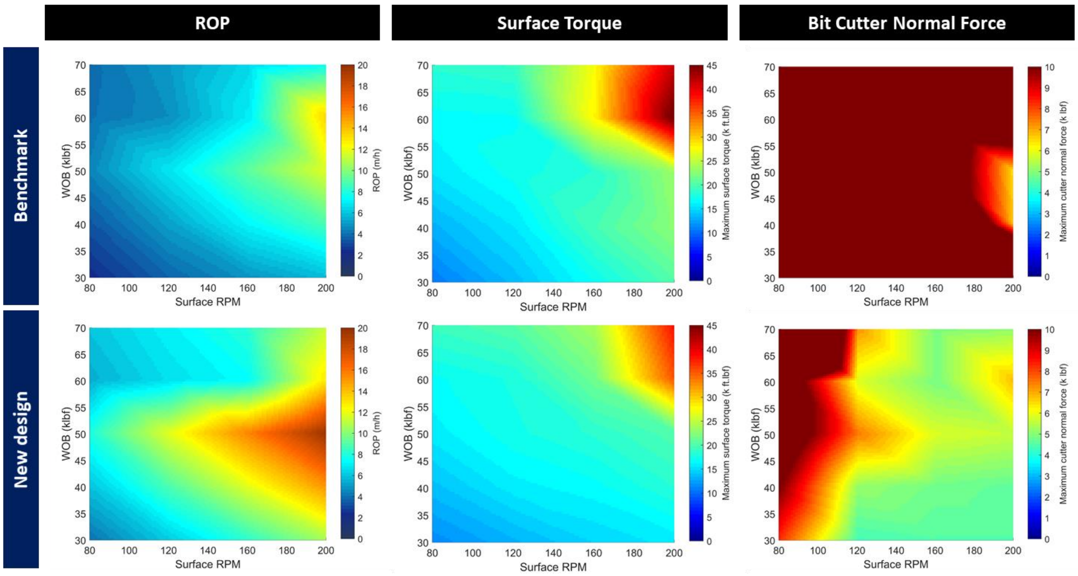

Fig. 8—Simulation results from comparing a benchmark bit (top row) with the new bit design (bottom row).

The analysis results showed that the 12 ¼-in. XZ813 Tailor-made bit is fit for use in the Brazilian presalt carbonates of the Búzios field. In addition, the BHA design was optimized and detailed drilling parameter plans were provided to the field crew.

Fit-for-Purpose 8 ½-in. Bit Design Selection Using Calibrated Presalt Virtual Rock

The design cycle for the 12 ¼-in. drill-bit development required an innovative approach. During the development campaign of the Búzios field, the operator changed the well design for some of the wells. As a result, a quick response from the service provider was necessary to provide a replacement for the current bit being used in the field. Due to time constraints, the service provider did not have sufficient time to design an entirely new bit for the new 8 ½-in. section. To overcome this challenge, the service provider's engineering team selected three available bits for comparison and evaluation. The objective of this effort was to select the most promising bit design currently available for the specific application in the Búzios field carbonate reservoirs. The bit selection was based on previous engineering experience gained from using these bits in challenging rock formations worldwide.

When comparing bits, dynamic simulations inside the 4D dynamic drilling simulation software were run under the actual field conditions (BHA, casing design, planned survey, drilling parameters, etc.). The simulated outputs for the comparison included drilling mechanics (surface torque, ROP), downhole vibration levels (axial, lateral, and stick/slip) at various BHA elements (logging while drilling, measurement while drilling), including the drill bit, and impact force at the drill-bit cutters. The impact force is important because it is the main risk for cutting structure degradation to occur when drilling carbonate reservoirs in the Brazilian presalt).

Even in the case of not having a calibrated rock model capable of reproducing the actual field conditions, it is possible to perform such a comparison. For this exercise, an existing rock in the catalog of available rock files would be chosen using engineering team experience in the field. In such a scenario, the rock file selected might not be representative of the actual drilling conditions because it does not use the knowledge captured from geology and petrophysical domains, which is one of the key benefits of having a calibrated model using this multidisciplinary approach. As an exercise, simulations were run using both calibrated and uncalibrated rocks. All of the simulated outputs were analyzed. The comparison of the impact force at the drill-bit cutters is shown in Fig. 9. When analyzing the simulation results using the uncalibrated rock, an improvement is noted, specifically the lower impact forces, which translates to longer bit runs resulting from the design options compared with the benchmark. Between design options #2 and #3 (see Fig. 9, top row), there is not considerable difference; therefore, both bits could be a potential candidate.

However, when observing the simulation results using the calibrated presalt virtual rock, the results are slightly different, showing a clear differentiation between all of the bits. Based on these results, the design option #2 was chosen for the run.

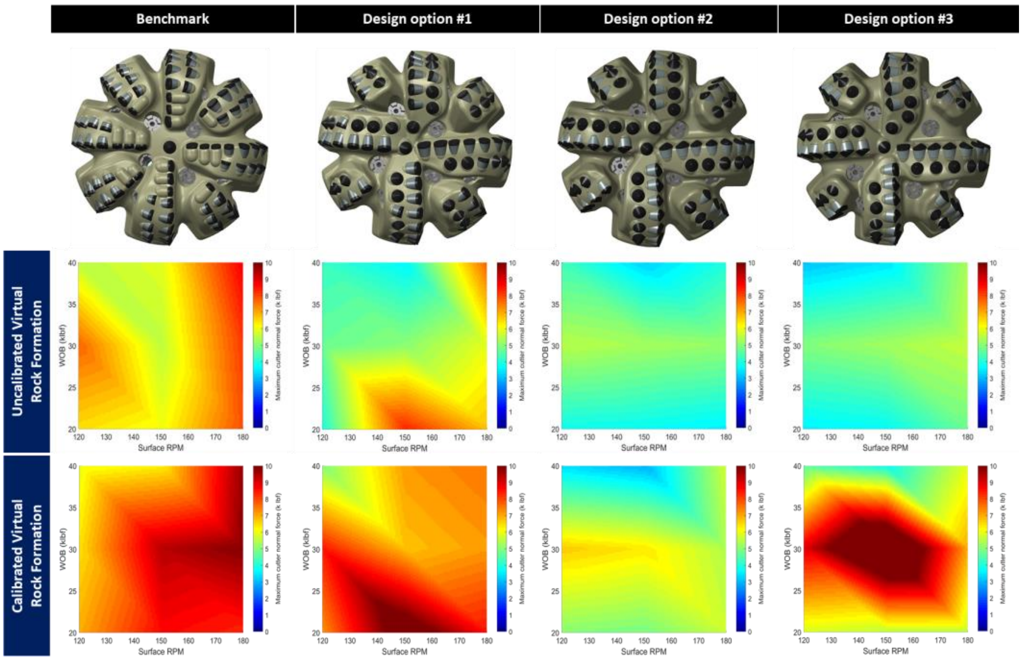

Fig. 9—Simulation results of drill-bit cutter normal force (risk of impact damage on cutters) with a comparison between different drill-bit designs over an uncalibrated virtual rock formation (top row) and calibrated virtual rock formation (bottom row).

RESULTS SUMMARY

Similar to the project development section of this paper, the results summary is also divided into two subsections. The first section concerns the 12¼-in. borehole section, which contains the bit design development followed by an innovative full digital cycle. The second section is the 8½-in. borehole section in which the calibrated presalt virtual rock from the catalog was used in applying the best fit-for-purpose drill bit.

For the 12¼-in. section, the operator selected the field test well based on the reservoir carbonate complexity. The challenge in this section was to increase average ROP and ensure drill-bit durability to successfully drill the presalt carbonates of the Barra Velha and Itapema formations. A comprehensive prejob study was performed, which included formation evaluation analysis of offset wells, stratigraphic zonation applied in the offset wells to estimate which drill zones to be drilled, and 4D dynamic drilling simulation to recommend best drilling parameters for each drill zone.

As of result, we were able to drill the entire presalt carbonate reservoir section in one bit run, drilling 327 m with an effective ROP of 10.1 m/h (average ROP of 9.8 m/h). Compared with the offset wells, this bit run offered an 89% improvement in drilled footage and 136% ROP (Fig. 10). The bit was pulled out of the hole and showed low-cutting structure wear after drilling the 327 m of the presalt carbonates. The overall surface torque and drilling dynamics (shock and vibration levels at the BHA) were significantly lower when compared with offset runs.

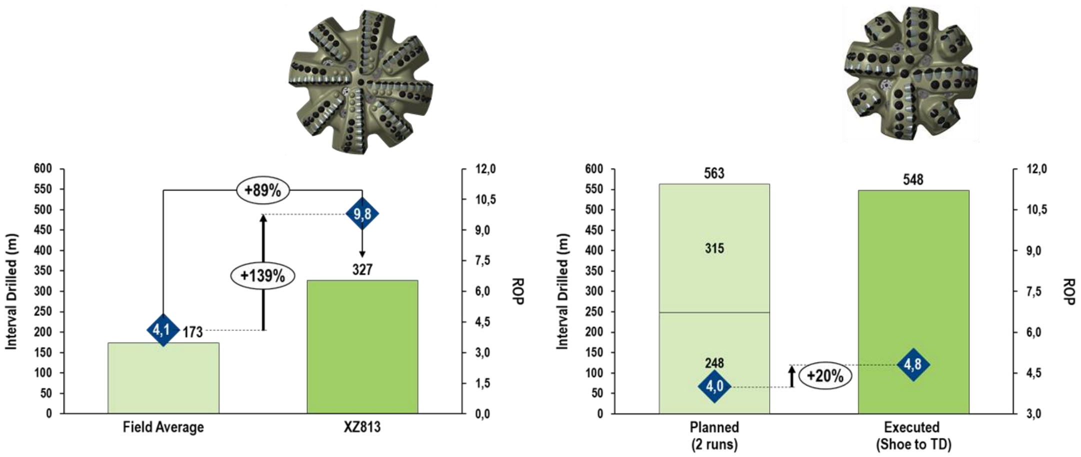

Fig. 10—Performance results in 12¼- in. section and 8½-in. section.

One important fact was observed when comparing the 4D dynamic drilling simulation results performed in the prejob with the field data. When comparing in what way drilling parameters (weight on bit and surface RPM) affect surface torque, ROP, and shock and vibration levels at the measurement-while-drilling and logging-while-drilling tools, there is very good agreement between prejob simulation predictions and the field data (see Fig. 11). At this time, it is important to emphasize that after this well was drilled, there was no effort made to validate the model calibration; just a simple comparison between simulation predictions and field data. This digital workflow made it possible to predict the drilling performance. It was even possible to predict cutting structure degradation using the calibrated 4D dynamic drilling simulation (Fig. 12).

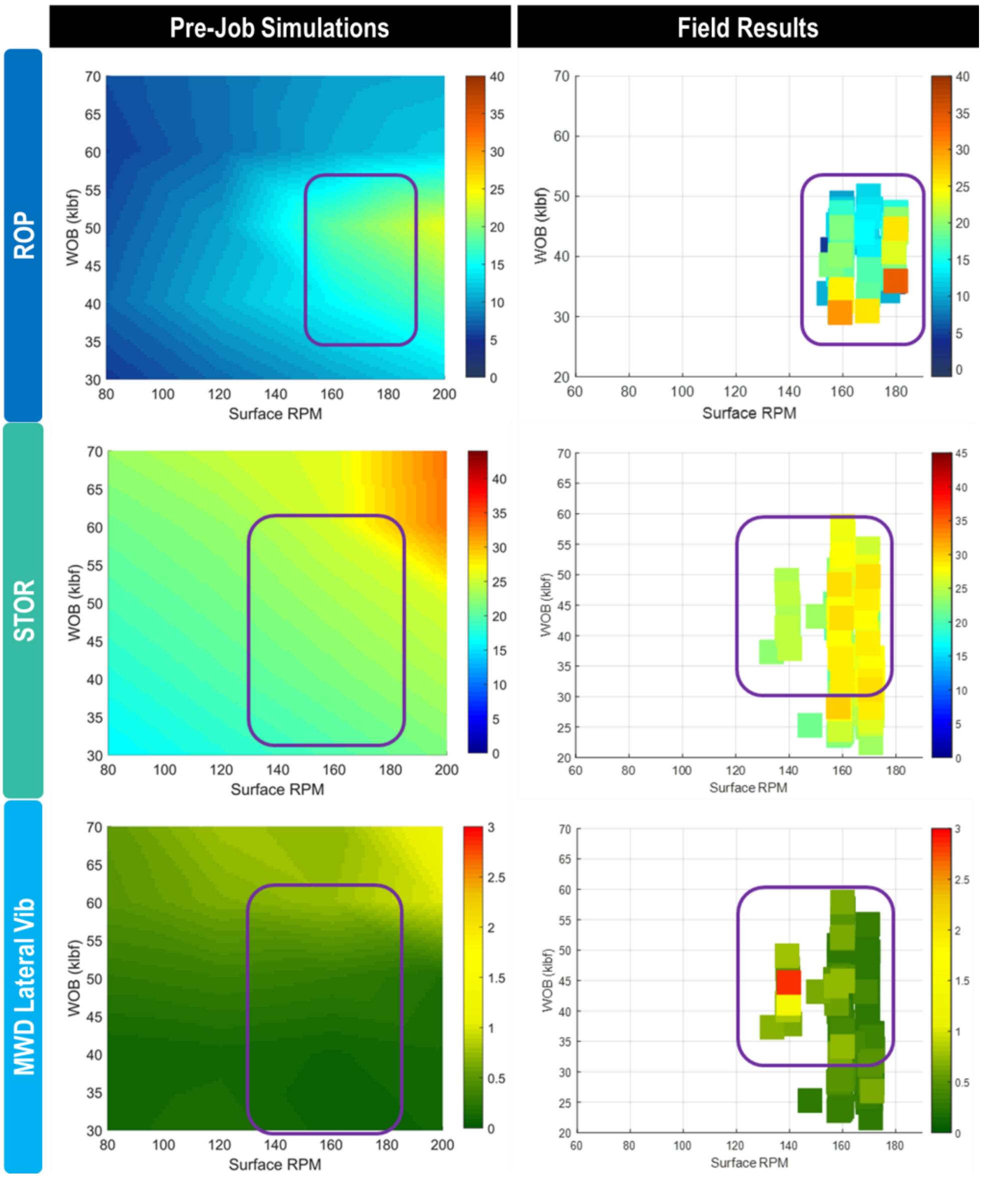

Fig. 11—Heat maps comparison between prejob simulations and the field results. ROP in m/h (top row); surface torque in k.ft/lbf (middle row); and measurement-while-drilling average lateral vibration levels in G- rms (bottom row). In all of the charts, the x-axis is surface RPM, and the y-axis is surface WOB

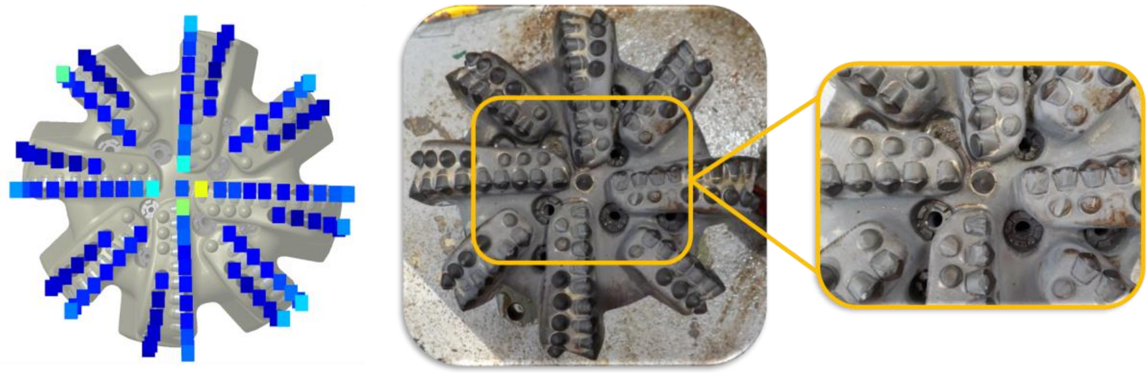

Fig. 12—Cutting structure degradation (impact damage) comparison between prejob simulations, and field results.

For the 8½-in. section, after selecting the bit, based on the calibrated rock formation inside the 4D drilling dynamics software, the results of the first well drilled exceeded operator expectations. The entire section was drilled in one bit run, whereas two bit runs were planned (Fig. 10). The bit drilled 548 m in this section with higher ROP than expected. This run represented a 23% reduction in rig hours, setting a new benchmark for the field and saving the operator significant time and costs. Combining the 12¼-in. and 8½in. bit run results, nine drilling runs followed using the improved workflow. The drilling runs averaged 300 m with a 6.5 m/h ROP, and two runs achieved double-digit ROP. These results represent a step change in drilling performance when compared with the offset wells drilled earlier not using this new digital workflow. Also, this performance improvement has not been matched in other blocks where the workflow was not applied.

CONCLUSIONS

This paper has presented the implementation of an improved, fully digital bit design workflow. The workflow integrates a calibrated 4D dynamic simulation model and petrotechnical expertise from drilling engineering, geomechanics, geology, and petrophysics groups to continue to push the drilling performance envelope in the challenging Brazilian presalt exploration and development. In a collaboration between different engineering teams, decisions included selecting a specific design features of the drill bit. The features, which encompassed cutters selection, cutting structure layout to the blade top features, were made inside the 4D dynamic simulation software. The results were tested in the presalt virtual rock, under the actual drilling conditions.

This system engineering workflow highlighted the integration efforts between multidisciplinary teams, leading to success in different borehole sizes when drilling the carbonate reservoirs in this challenging Brazilian presalt interval. In the 12¼-in. borehole, an innovative bit design produced an 89% improvement in footage drilled and 136% improvement in ROP compared with the field average. In the 8½-in. borehole, a thorough investigation of current available drill bits led to a customized bit selection, resulting in one-bit run interval to reach section total depth.

ACKNOWLEDGMENTS

The author wishes to thank SLB for permission to publish this work.

REFERENCES

Aguiar, R.R., Hbaieb, S., Azar, M. et al. 2016. Optimization of the PDC/ CDE Hybrid Cutting Structure Developed to Drill the Pre-salt Carbonates Reservoirs Offshore Brazil. Paper presented at the Rio Oil & Gas Expo and Conference, Rio de Janeiro, Brazil, 24–27 October. IBP1296_16.

Aguiar, R.R., Tocantins, J.P., Marquinez, V. et al. 2019. Drilling Optimization Using Model-Based Design and Stratigraphic Zonation: Successful Application in Brazilian Deep Water Pre-Salt Carbonate. Paper presented at the SPE ATCE, Alberta, Calgary, Canada, 30 September–2 October. SPE-196057-MS. https://doi.org/10.2118/196057-MS.

Aslaksen, H., Annand, M., Duncan, R. et al. 2006. Integrated FEA Modeling Offers System Approach to Drillstring Optimization. Paper presented at the SPE/IADC Drilling Conference, Miami Beach, FL, 21–23 February. IADC/SPE 99018-MS.

Azar, M., White, A., Segal, S. et al. 2013. Pointing Towards Improved PDC Bit Performance: Innovative Conical Shaped Polycrystalline Diamond Element Achieves Higher ROP and Total Footage. Paper presented at the SPE/IADC Drilling Conference, Amsterdam, The Netherlands, 5–7 March. SPE-163521-MS. https//doi.org/10.2118/163521-MS.

Bertarelli, M., Duran, R., Tocantins, J.P. et al. 2020. Innovative Technologies Drive Benchmark Performance Drilling Challenging Caipipendi Block in Bolivia. Paper presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Virtual, 27–31 July. SPE-198984-MS. https://doi.org/10.2118/198984-MS.

Compton, M., Verano, F., Nelson, G. et al. 2010. Managing Downhole Vibrations for Hole-Enlargement-While-Drilling in Deepwater Environment: A Proven Approach Utilizing Drillstring Dynamics Model. Paper presented at the SPE Latin American & Caribbean Petroleum Engineering Conference. Lima, Peru, 1–3 December. SPE 139234-MS. https://doi.org/10.2118/139234-MS.

Hbaieb, S., Pirovolou, D., Fonseca, C. Et al. 2012. Stratigraphic Zonation Applied for Drillability - Motivation and Proposed Workflow. Paper presented at the Rio Oil & Gas Expo and Conference, Rio de Janeiro, Brazil. IBP17325_12.

Pak, M., Azar, M., and Pahl, J. 2016. Conical Diamond Element Enables PDC Bit to Efficiently Drill Chert Interval at High ROP Replacing Turbine/Impregnated BHA. Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA. SPE-178765-MS. https://doi.org/10.2118/178765-MS.

Peixoto Filho, F.T. and De Souza, I.S. 2010. Brazilian Pre-Salt: The Challenges of Coring at a New Frontier. Paper presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Lima, Peru, 1–3 December. SPE 139195-MS. https://doi.org/10.2118/139195-MS.

Wang, Y., Shen, Y., Charter, M. et al.2014. High Frequency Vibration Measurement Coupled with Time-Based Dynamic Simulations: New System to Predict/Solve Instability Issues. Paper presented at the SPE Annual Technical Conference and Exhibition. Amsterdam, The Netherland, 27–29 October. SPE 170708-MS. https://doi.org/20.2118/170708-MS.

Wright, V. and Barnett, A. 2015. An abiotic model for the development of textures in some South Atlantic early Cretaceous lacustrine carbonates. Geological Society, London, Special Publications, 418 (2012): 1–11.

RESPONSIBILITY NOTICE