AADE-24-FTCE-020

Integral drilling technique for heterogeneous formation sections: Converting challenges into success

Nelson Alfonzo, Juan Carlos Minda and Hector Gonzalez, Saudi Aramco

Abstract

Dealing with highly heterogeneous sections of brittle formations presents several tasks, including wellbore instability, abrasiveness, vibrations, stick and slip, losses, high pressure, highly compacted rocks, low ROP, and above all, sloughing rock, and puts a drilling team to a technically demanding test in field appraisal and development campaigns. This paper describes the improvements and strategies made to overcome such tasks and drills them into one successful intermediate section and each well.

Heterogeneous formations, encountering losses, were usually drilled with several bit trips or in several offset sections. Now, to successfully drill across these formations in one section, modified bits together with high-torque low-speed motors, drilling reports review of geomechanical-related issues, and formation-specific drilling parameters have been complemented with a MUD strategy that switched from water-based mud (WBM) to oil-based mud (OBM) before penetrating the high shear failure formations and keeping it until TD. This provides stability and lubricity to the hole, improves torque, shock, and vibration conditions, and facilitates reaching the TD of the section. Also, the open-hole displacement operations allow for continuous drilling operation with no associated flat-time or wellbore reconditioning.

The incorporation of the drilling strategies allows for drilling across the formations in a single run, consistently, and successfully in multiple wells. Furthermore, the on-location storage, recycling, and conditioning of the OBM have lowered the overall project carbon footprint. Looking forward, the addition of a geomechanical modeling will address an optimal wellbore stability window, enhancing operational efficiency.

Keywords: open hole displacement, instability, drilling optimization, OBM, WBM, HPWBM

Introduction

Appraisal and development projects face the constant drive to achieve cost and time optimization to allow the financial viability of O&G field developments. This requires minimizing operational complexity and maximizing on resource utilization while drilling the wells. Thus, well designs encompassing multiple formations posing different operational challenges represent a common situation.

For a drilling team to be successful when drilling long sections (5,000 ft or longer) through high shear failure shale, highly compacted, interbedded heterogeneous formations with all sorts of open hole troubles such as abrasiveness, vibrations, stick and slip, losses, high pressure, low ROP, and sloughing shales. Several drilling strategies have to be implemented to overcome such difficulties and drill through these environments with one drilling string, especially using only one bit to drill shoe to shoe, and above all, to consistently be able to replicate the runs over and over successfully. This approach takes more importance in multi-well field appraisal and developments where the swift lesson learned deployment could represent a significant factor in project success.

From the fluids point of view, drilling in the region tends to pose the challenge of combining low pressure with pressurized layers within the same well sections. Combinations of lost circulation and strengthening materials have helped to overcome them with suitable success (Vickers et al. 2007). As discussed by Musa et al, 2022; proper selection of the preventive treatment helps to improve operational and engineering performance. For this project, continuous application matched the overall strategy and operational requirements.

In terms of fluid management, open-hole displacements are not common in intermediate sections; gradual fluid conversion tends to be a well-known practice in non-productive formations where the fluid parameters match formation requirements as it goes deeper and tends to maintain the same base fluid. Open-hole displacements mostly take place in reservoir drilling (Bloys et al. 1995) or in combined sections of non-productive and reservoir layers (Reeve et al. 2002). Also, as a contingency measure when the wellbore instability or section objectives would not be achieved under programmed parameters. When it is not planned, it represents a costly measure involving considerable downtime while conditioning surface equipment for preparing an alternative base fluid, besides displacement and open-hole conditioning time.

Lastly, lowering the environmental footprint, minimizing logistical requirements, and cost-optimizing tend to represent major considerations when selecting and managing a drilling fluid. Options enabling the carrying over of a similar fluid between consecutive sections and wells embody a desirable situation in well construction, and field developments. This could reduce the amount of required materials, volume, logistics, and equipment involved while drilling a multi-well campaign.

Problem and solution

A geographical area with several satellite fields was identified as a candidate for further field development. Previous appraisal and development wells confronted drilling performance and formation-related challenges. In order to overcome them and allow successful project delivery, a multi-disciplinary team worked in a synergistic manner on the main affected areas. The following section describes previous conditions and deployed approaches to achieve it.

Drilling Optimization

1. Bit considerations

When using unoptimized approaches, the target heterogeneous formations with abrasive sandstone, with carbonates where losses happened at any point, with massively unstable, very reactive to water shale, and with compacted limestone and/or dolomitic limestone would be drilled with several bit trips or splitting in two sections (Figures 1 and 2). Bits had several damages and severe dull gradings; stuck pipe events would be repetitive, and poor ROP would be the constant reason to pull the string out of the hole, affecting overall well construction performance.

Figure 1. Damaged cutters in previous bit runs

Very common chipped cutters on all blades; significant wear on main and backup cutters, mainly on the nose and shoulder areas. Single-row or double-row protected bits on rotary or motor BHAs would equally fail to finish the section.

Figure 2. Damaged bit structure previous runs

2. BHA considerations

Detailed analysis of the real-time data reflected:

- Highly abrasive sandstone formations are being penetrated and drilled with the same high drilling parameters as softer limestone or dolomitic limestone formations.
- High lateral vibration and stick and slip when drilling the highly abrasive sandstone formations.
- Significantly high spikes of stick and slip occurred when drilling the highly compacted and interbedded formations with high WOB to compensate for the marked ROP drop; however, the bit damage was already so significant that it hindered finishing the section off.
- All the previously used BHA configurations and the drilling parameters that were used with those BHAs produced a medium to high level of lateral vibration.
- Also, all the previously used BHA had very abnormal and chaotic string stability; see Figure 3.

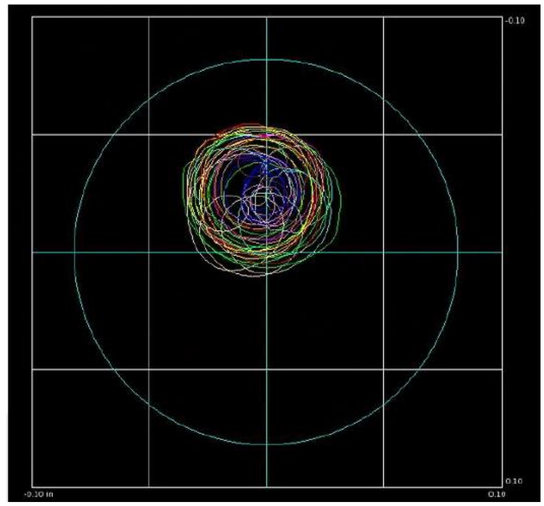

Figure 3. BHA rotation profile of previous well

As a consequence, ROP would drop significantly, showing severe bit damage. Since drilling parameters would be kept the same, bits would be pulled and changed several times.

After detailed analysis of historical data and engineering assessment by the drilling team, a new BHA configuration and drilling strategy were proposed and deployed.

The optimized proposed drilling process to drill successfully across these packages in one section uses only one packed drilling string, one abrasive and impact-resistant protected bit, and a high-torque low-speed motor BHA. This mechanical design applies a formation-specific set of drilling parameters to assure the bit is not destroyed when drilling through the highly abrasive formations.

The extra protected bits included new cutter technology to withstand abrasiveness and high impact, controlled TFA, along with the formation-specific road maps managing surface RPM, WOB, and flow rates to prevent bit damage across the abrasive sandstone. Average ROP is maintained with the motor at a pre-determined speed, so the total RPM on the bit is known to be at a specific value that has been found not to erode the bit cutting structure until the abrasive sandstone package is drilled. The new strategy guarantees enough remaining cutting structure on the bit to continue drilling through the highly compacted and hard lower formations.

When the remaining cutting structure of the bit is still in good condition, even though the stick and slip; axial and lateral vibration seem to be high, the ROP is not as impacted as much as when the bit has already been damaged.

The rotation momentum of the BHA has been analyzed, simulated, and tested; see Figure 4. The surface RPM is planned for each formation and kept at specific values to satisfy different conditions, such as low RPM for avoiding erosion across the abrasive areas and higher RMP values to improve ROP through highly compacted formations. Although all the RPM ranges would be within the recommended simulated rotation momentum of the BHA, with accepted side forces and BHA displacements showing no issues and an overall normal rotation print of the BHA.

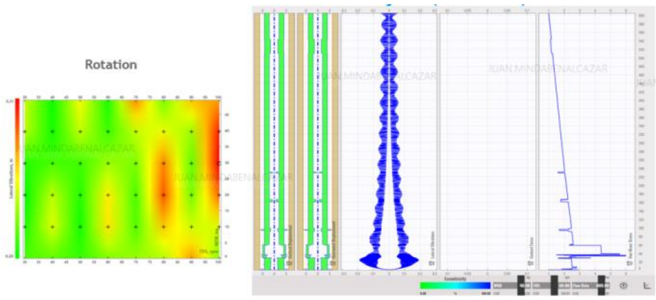

Figure 4. BHA rotation momentum analysis of previous wells

The rotation simulation and RPM values to be used in the road map play a paramount role in protecting the bit across the abrasive sections. If the RPM values are exceeded, the bit will not finish the section, so if a rotary BHA is used, the top drive RPM are fixed to a maximum value; if a directional BHA is used the top drive RMP is fixed. Likewise, the flow rate is fixed, so the total RPM value is fixed for rotation and sliding intervals across the abrasive formations. Figure 5 shows an optimized well reflecting more controlled BHA momentum throughout the section.

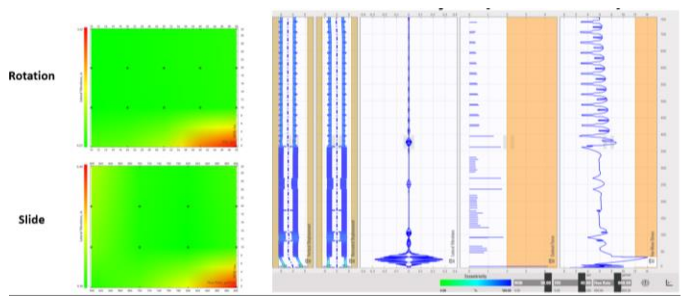

Figure 5. BHA rotation momentum analysis of optimized wells

The normal rotation momentum of the BHA is a key factor; the stiffness ratio of the BHA must be controlled and kept low, as per the technical recommendation for harsh drilling environments according to best drilling practices. Keeping normal transitions among the BHA components drill collars, heavy weight drill pipe and drill pipe is key to avoiding excessive torque fluctuations and avoiding twist-off events.

Optimized wells have shown more efficient drilling dynamics with lower vibration, as shown in figures 6 and 7.

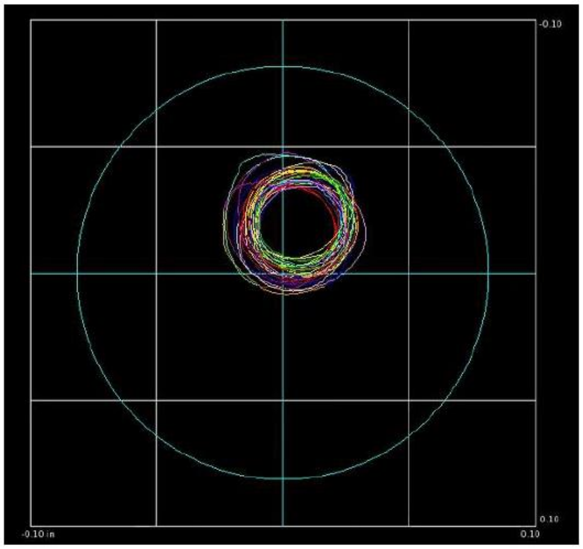

Figure 6. BHA rotation momentum analysis of optimized wells

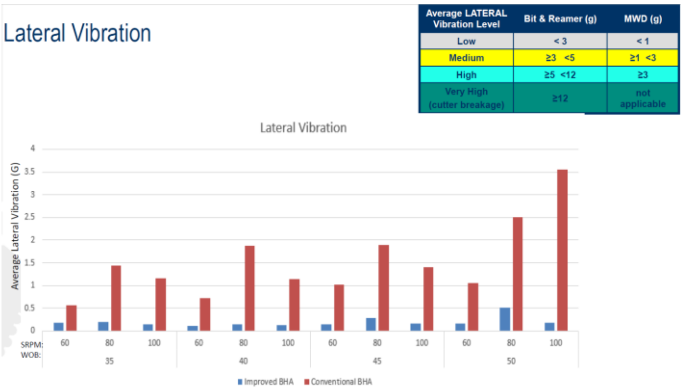

Figure 7. BHA lateral vibration comparison

Finally, the incorporation of the improved, extra-protected bits with new cutter technology to withstand abrasiveness and high impact, along with the formation-specific road maps managing RPM, WOB, and flow rates to prevent bit damage across the abrasive sandstone formations, and the improved configuration of rotary or motor-packed BHAs with the correct stiffness ratio and control of rotation momentum, allow for a significantly better drilling process, finishing massive sections with an acceptable average ROP and only ONE BHA.

3. Drilling Fluids considerations

Historical applications aiming to use WBM have failed to deliver suitable drilling performance and a stable wellbore without facing unplanned sidetracks in the studied fields. A variety of WBM designs have been considered, including High Performance Water Based Mud (HPWBM), with no further success. Faced problems included hole instability, total losses, and stuck pipe incidents in more than 50 % of wells drilled.

Thus, the intermediate section has been treated as two sections in one, aiming for an OBM open hole displacement before a mechanically and reactive formation marker provides suitable control of potential downhole losses. The approach addresses the high risk of total losses in the first part of the hole with a treated HPWBM guaranteeing drillability; once confirmed suitable conditions paved the road for OBM deployment in a prong to collapse and abrasive lower formations while maintaining maximum lubricity, chemical and mechanical stabilization.

The selected HPWBM complied with the following formulation:

Table 1. HPWBM fluid formulations

Additive	Units	From	To	Function
Drill Water	Barrels	0.87		Base fluid
Caustic Soda	Pounds per barrel	0.25	0.5	pH Control
Soda Ash	Pounds per barrel	0.25	0.5	Contaminant Remover
Bentonite	Pounds per barrel	5.0	7.5	Viscosifier
Xantham Gum	Pounds per barrel	0.5	1.5	Viscosifier
NaCl	Pounds per barrel	20	24	Weighting Material
Sized $CaCO_3$	Pounds per barrel	45	60	Bridging Material
Granulated Cellulose	Pounds per barrel	3.0	4.0	LCM
Starch	Pounds per barrel	4.0	6.0	Fluid Loss Control
PHPA	Pounds per barrel	1.0	1.5	Encapsulator
Polyamine	Volume percent	2.0	3.0	Shale Inhibitor
Barite	Pounds per barrel	As per Mud Weight		Weighting Material

Table 2. HPWBM property ranges

Property	Unit	Minimum	Maximum
Mud Weight	Pcf	75	78
Funnel Viscosity	Sec/qt	50	60
Plastic Viscosity	Cp	14	22
Yield Point	Lbs-f/100ft^2	19	27
6 rpm	-	10	12
Gels: 10 sec/10 min/30 min	Lbs-f/100ft^2	9/10/14	11/13/16
pH	-	9.0	10.0
Chlorides	mg/L	40 K	55 K
API Fluid Loss	mL/30 min	4.0	5.0
HTHP Fluid Loss at 280° F and 500 psi	mL/30 min	16.0	18.0

HPWBM fluids in the proposed wells have been managed within the programmed window without major deviations or obstacles from the property values or fluid-related operations.

ECD management, hole cleaning enhancement, and background lost circulation treatments complemented fluid property management. These measures helped to diminish the typical loss circulation occurrence, guaranteeing OBM deployment without incurring pre-existing total loss scenarios. Background treatments considered 20 - 40 pounds per barrel of a blend of Nut Plug, Mica Fine, sized cellulose fiber and sized flaky CaCO3. A remedial plan was set in place for middle to severe losses that comprise increasing concentrations of LCM blends limited by downhole tool restrictions, with subsequent usage of crosslinked pills or cement plugs, depending on the scenario.

Also, bit balling represents a major risk for the section, so tenso-active agents are added through the pipe in each connection, diminishing incidence occurrence.

Prior to reaching the formation marker and after ensuring minimum downhole losses, the HPWBM is displaced in the open hole to OBM as per programmed parameters.

Open-hole displacement is considered a direct transition from HPWBM to OBM employing an inhibited water cushion of 50 bbls, or enough to cover 1,000 ft of annular volume, and 50 bbls of viscosified OBM as a spacer. The operation is carried on the fly with no drilling stoppage, and no signs of wellbore instability or interphase creation. All wells drilled with this approach have shown a minimum level of interphase or OBM contamination.

Planned OBM is prepared off-line and available recycled volume is incorporated to achieve programmed properties in a faster manner. The OBM formulation was as follows:

Table 3. OBM fluid formulation

Additive	Units	From	To	Function
Diesel	Barrels	0.61		Base fluid
Primary Emulsifier	Gallon per barrel	0.9	1.2	Emulsifier
Lime	Pounds per barrel	5.0	6.0	Alkalinity Control
Brine		0.18	0.20	Weighting Material
Organophilic Clay	Pounds per barrel	6.0	8.0	Viscosifier
Secondary Emulsifier	Gallon per barrel	0.3	0.5	Emulsifier
Treated Lignite	Pounds per barrel	6.0	8.0	Fluid Loss Control
Sized $CaCO_3$	Pounds per barrel	As per Mud Weight		Weighting Material

Table 4. OBM properties

Property	Unit	Minimum	Maximum
Mud Weight	Pcf	81	83
Plastic Viscosity	Cp	24	27
Yield Point	Lbs-f/100ft^2	19	24
6 rpm	-	10	14
Low Shear Yield Point	Lbs-f/100ft^2	7	10
Oil Water Ratio	-	76/24	80/20
Water Phase Salinity	mg/L	240 K	250 K
ES	Volt	600	850
HTHP Fluid Loss at 280° F and 500 psi	mL/30 min	2.0	3.0

As HPWBM, selected OBM were managed within the programmed envelope without observing any significant deviation either in fluid management or fluid-related operational events.

OBM was loaded with 20 - 40 ppb background LCM comprising sized fiber, a blended sealant specialty product, and sized CaCO3.

The OBM is recycled and kept in an on-location storage and conditioning small OBM plant, which allows a coordinated sharing event of the OBM requiring transportation, avoiding OBM additional preparation, and significantly reducing mud treatment and generated volume.

Also, OBM is designed with acid-soluble materials or prongs for easy elimination, allowing further recycling and avoiding the need to handle different types of drilling fluids in the remaining hole sections. This allows a significant simplification of operational handling, waste generation, and the overall carbon footprint, as well as a reduction in overall operational costs.

Way Forward

The drilling team will focus on continued optimizing of BHA and drilling parameters to achieve faster drilling across the massive and highly heterogeneous formation packages in one section with one BHA, consistently and successfully. New bit designs with higher protection and impact resistance are under evaluation for trial. Also, more robust downhole motors complement the expected new evaluations.

Future fluid strategy will assess enhancing OBM solid tolerance to allow carrying over further through multiple wells and sections. At the moment, the concept has been successful in 3–4 wells along with two consecutive sections, and the plan is to extend it to more wells and even longer lower sections. ECD management has helped to lower the lost circulation risk; however, further adjustments could help to achieve even superior drilling performance without sacrificing this gain.

The inclusion of geomechanics in future wells would be an important factor to consider. Geomechanical modeling plays a crucial role in improving drilling efficiency by providing insights into the mechanical behavior of subsurface formations. A 1D Mechanical Earth Model (1DMEM) will assist in determining the appropriate mud weight to balance the formation pressure and the rock strength. It will help assess the mechanical impact of drilling, allowing us to choose the optimal well path in concordance with the in-situ stresses. Furthermore, it will drive the understanding of the interaction between the wellbore and surrounding rock formations, aiming to optimize well delivery as reported by Chatterjee, et al. (2021).

Conclusions

Extensive engineering analysis, design, and simulations have allowed drilling highly heterogeneous formation packages in one section with one BHA and a fluid open hole displacement, consistently and successfully. This effort includes multiple field trials covering the following aspects:

- Bit protection and cutting structure.
- BHA configuration.
- Formation-specific drilling parameters.
- Drilling fluid management: WBM open hole displacement by OBM along with loss circulation management.

The current strategy has improved previous well intermediate section drilling performance with shorter overall operational time.

Upcoming well designs and operational planning are incorporating this strategy to enable faster and more efficient well deliveries. Also, the strategy has demonstrated value aligning the field development with company goals of minimizing environmental impact through lowering carbon footprint and waste generation. The proposed inclusion of a 1DMEM will enable the drilling team to make informed decisions, optimize drilling parameters, and mitigate risks..

Nomenclature

RPM – Rotation per minute
WOB – Weight on Bit
ROP – Rate of penetration
BHA – Bottom Hole Assembly
OBM – Oil Based Mud
WBM – Water Based Mud
HPWBM – High Performance Water Based Mud
1DMEM – 1D Mechanical Earth Model

References

1. Bloys, J. B., Murphy, J., Weingarten, J. S., and M. W. Wheatall. "Drilling and Completing Wells for High Productivity in the Point Mclntyre Field: Strategy, Implementation and Verification." Paper presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, October 1995. doi: https://doi.org/10.2118/30461-MS
2. Reeve, Jack, Jones, Tom, McNair, Gary, and Hu Jia Pin. "One Hole Section-Two Fluids: Optimizing Drilling and Drill In Through Reverse Sequence Solution Engineering." Paper presented at the IADC/SPE Asia Pacific Drilling Technology, Jakarta, Indonesia, September 2002. doi: https://doi.org/10.2118/77191-MS
3. Vickers, S., Cowie, M., Burgess, M. et al, " The Application Of Specifically Formulated Bridging Materials To Successfully Reduce Pore Pressure Transmission To Enable Depleted Fractured Reservoirs To Be Drilled And Produced Without Incurring Formation Damage." Paper presented at the European Formation Damage Conference, Scheveningen, SPE-107753, 30 May-1 June 2007.
4. Chatterjee, Avirup , Ghosh, Amitava , and Priveen Raj Santha Moorthy. "Role of Geomechanics in Identification of Possible Mechanisms for Non-productive Times NPT and Improving Drilling Operations in a Mature Field in Offshore Sarawak, Malaysia." Paper presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Virtual, October 2021. doi: https://doi.org/10.2118/205546-MS
5. Musa, I., Hale, A. and El Mohandes, M. " Wellbore Strengthening – Continuous Application or Sweep as Needed? " Paper presented at AADE Fluids Technical Conference and Exhibition, Houston, USA, April 19-20, 2022.