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Tackling wellbore difficulties for drilling deviated and horizontal wells

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Abstract. Future development plans are often being continued during production. These plans includes wells repair, reservoir enhancements, or new development wells in order to increase the field production. Therefore, the main objective of this paper is to tackle deviated and horizontal wellbore difficulties in GOF field. Specific drilling hole problems are addressed and reviewed. Additionally, proposed solutions are suggested to improve wellbore stability and select the appropriate hole cleaning drilling practices, based on offset data for drilling the new development wells of Gulf Offshore Field (GOF) without instability difficulties. Overview of this field is discussed including geological column, wells locations, and contour maps. Offset wells data are completely analyzed. Drilling fluids are selected with their properties that avoid wellbore obstructions. Moreover, deviated and horizontal trajectories are optimized for the new development wells. Finally, the best drilling practices are hence recommended.

Keywords: trajectory optimization, wellbore problems, drilling practices, horizontal wells.

Introduction

Oil fields are often required to be developed from time to time. One of the developments is drilling activity. Development wells are performed in order to enhance the productivity of the oil field. Therefore, offset wells data surrounding the drilling area should be collected in order to be checked and analyzed. After that, production plans and development strategy are obviously determined. The importance of offset wells data appears during drilling new exploratory or development wells. Adams [1] presented two different company strategies about how the offset data of near wells influence drilling performance and operations. One of the two strategies was to maximize the benefit from the offset wells data by buying these data with \$800 and performing the drilling plan, while the other was to do

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nothing and to perform the drilling plan without obtaining the offset data. During drilling, the first helped to reach target safely while the other was exposed to blowout, destroying rig and persons and the final settlement by the insurance company was over \$16 million instead of \$800.

Based on offset wells data; stratigraphy geological column, formation types, layers depth, drilling problems, drilling operations, pressure profiles, formation troubles and stability etc. may be determined and known for new wells. However, the wellbores instability happen due to several causes which have previously been discussed by several textbooks and scientific articles [2-12]. Additionally, one of the drilling problems, when encountered, can be very costly and influence the wells stability if it is not treated well such as loss of circulation (LOC) and pipe sticking, hole enlargement etc. Most of wellbore stability models dealing with fracturing loss were previously presented [7-12]. Additionally, Halafawi and Avram [10-11] presented and identified the risk assessment for drilling problems and operations with field case studies.

In order to estimate the possible hazards and risks for controlling and reaching the target safely with optimum profile, an understanding of wellbore problems, their causes, their anticipation and planning for solutions is a key factor. Therefore, the stability and the trajectory optimization of new GOF development wells are also required to be accurately determined in order to drill them safely.

In this article, complete drilling activities of GOF wells are addressed. The main issues of wells production, wellbore problems, their effects on well design, possible solutions, and preventive measures are taken into account. Offset wells drilling data are analyzed. Major problems of drilling wells are identified, detected, and treated. Additionally, deviated and horizontal wellbores are optimized based on tackling trajectory obstructions.

Drilling well problems

During drilling operations, some types of the drilling problems will almost certainly occur, even in very carefully planned wells. The reason is that geological conditions for two wells that are near each other may differ (nonhomogeneous formation); therefore, different problems can be encountered. The key to success in achieving well objectives is to design drilling programs based on anticipation of potential hole problems, rather than on containment and caution. Drilling problems, when encountered, can be very costly and they are pipe sticking, lost circulation, hole deviation, pipe failures, borehole instability, mud contamination, formation damage, hole cleaning, H₂S-bearing formations and shallow gas, and equipment & personnel-related problems (Fig.1). Details of the preceded problems are introduced and discussed by several authors [1-12].

Well profiles for a wellbore trajectory optimization

The mathematical trajectory planning calculation and equations are the same as those used in directional calculations, presented by many authors [1-7, 13-15]. However, there is an exception that the primary unknown in the combination trajectory plan is the depth of kick off point (KOP). Additionally, the problems result in horizontal turn trajectory, vertical turn computations, mud weight selection, building 3D profile and survey methods selection.

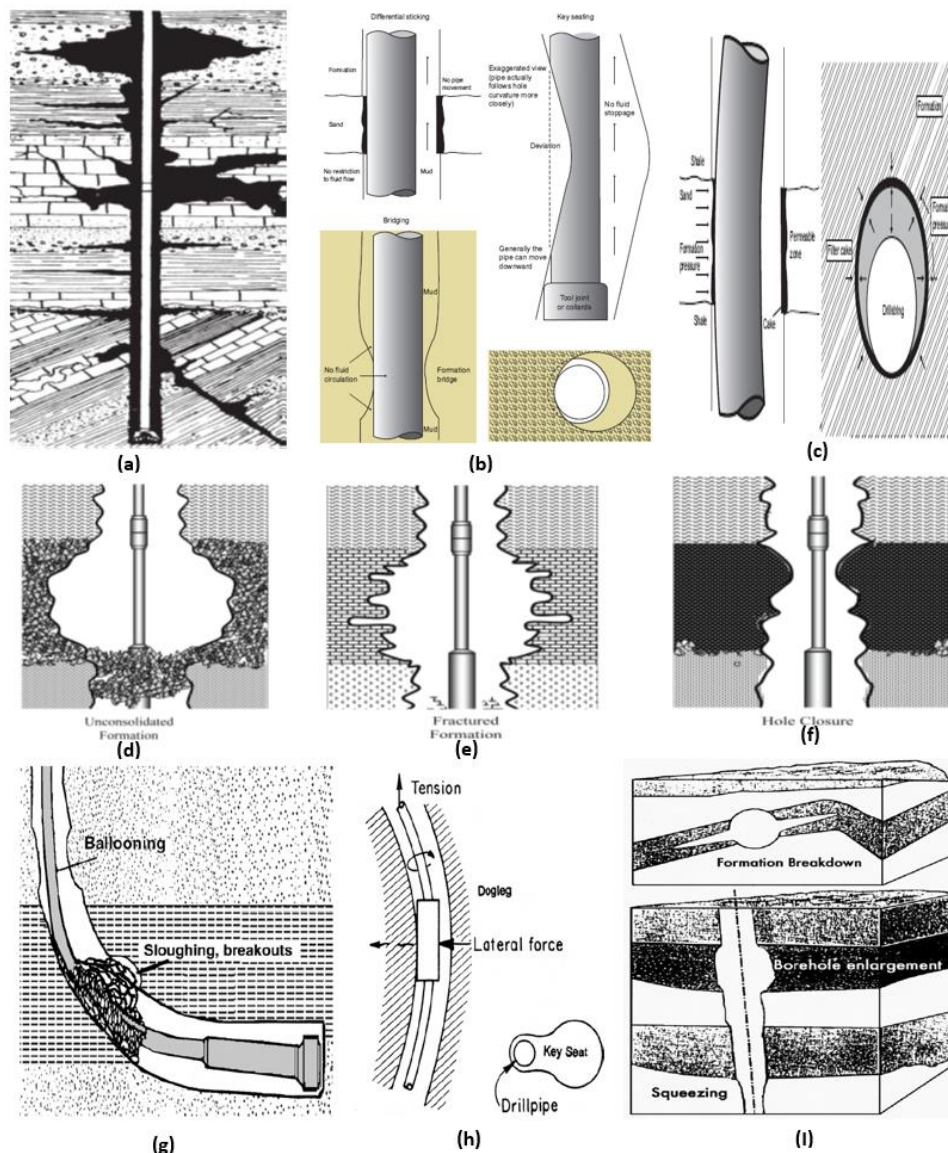


Fig. 1. Drilling Problems (a, b, c) [7], (d, e, f) [2], and (g, h, i) [14]

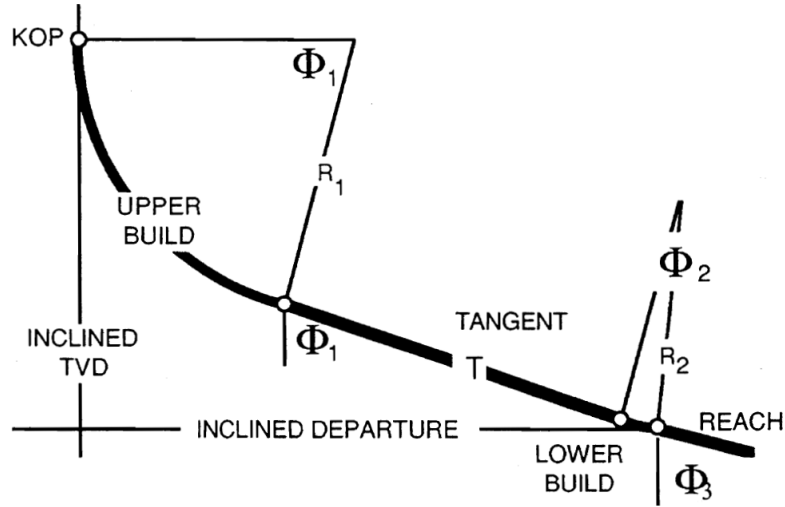


Fig. 2. Horizontal well Profile [15-16]

KOP, Horizontal Turn Trajectory, and Vertical Turn Determination. Authors [13-16] discussed the mathematics for determining KOP in the combination trajectory of horizontal well plan as follows:

$$\text{Inclined TVD} = R_1 \sin \Phi_1 + T \cos \Phi_1 + R_2 (\sin \Phi_3 - \sin \Phi_1) \quad (1)$$

$$\text{Inclined DEP} = R_1 (1 - \cos \Phi_1) + T \sin \Phi_1 + R_2 (\cos \Phi_1 - \cos \Phi_3) \quad (2)$$

$$\text{Inclined MD} = R_1 \Phi_1 + T + R_2 \Phi_2 \quad (3)$$

$$\text{Departure of the REACH} = \text{REACH} \times \sin \Phi_3 \quad (4)$$

$$\text{Change in TVD of the REACH} = \text{REACH} \times \cos \Phi_3 \quad (5)$$

where

REACH = The along the hole distance (MD) of portion of the hole which is normally thought to be horizontal

MD = Measured depth, ft

Dep = Departure length, ft

T = Tangent length, ft

R₁ = Radius of curvature for upper build, ft

R₂ = Radius of curvature for lower build, ft

Φ = Inclination angle for position 1, 2, and 3 ($\Phi_3 = 90^\circ$), degrees

The sets of the above equations are solved simultaneously to determine KOP (Fig. 2). The appeared problems during planning a horizontal turn and a vertical turn in the horizontal section of the planned wellbore are determined and solved [13-16]

Mud Weights Selection for Horizontal Wellbore. Methods of mud weight choice in vertical well are not the same as in directional or horizontal holes. Consequently, Mitchell [2] presented a method for determining mud densities (ppg) in order to stabilize deviated and horizontal wells:

$$MW_{\text{horizontal}} = MW_{\text{vertical}} + (OBW - LOT) \frac{1 - \cos 2\phi}{1.6} \quad (6)$$

where

WM = Mud weight, ppg,

OBW = Overburden weight (Overburden stress), ppg,

LOT = Leak off test value, ppg,

φ = Inclination, degrees.

In order to perform wellbore trajectory optimization, it is required to determine the best well profile survey parameters. The five methods [7], which are used to implement survey calculations, are average angle method (AAM), radius of curvature (RCM), constant build and turn rate (CBTM), constant curvature and build rate (CCBM) (constant tool face), and minimum curvature method (MCM).. However, MCM is the most used by the petroleum industry for both well-trajectory planning and directional-survey evaluation [7]. Recently, Sawaryn and Thorogood [17] presented algorithms for directional-well planning and deflection-tool orientation. MCM equations are simply deduced from these algorithms:

$$RF = \frac{\Delta MD}{\beta} \tan \frac{\beta}{2} \quad (7)$$

$$\Delta X = (\sin \varphi_1 \cos \vartheta_1 + \sin \varphi_2 \cos \vartheta_2) RF \quad (8)$$

$$\Delta Y = (\sin \varphi_1 \sin \vartheta_1 + \sin \varphi_2 \sin \vartheta_2) RF \quad (9)$$

$$\Delta Z = (\cos \varphi_1 + \cos \varphi_2) RF \quad (10)$$

where RF = Ratio Factor, β = Dog-leg angle, deg, φ = inclination angle, deg, ϑ = Azimuth angle, deg.

Offshore gof field description

GOF field is an offshore oil reservoir field with various faults. Geological column for the GOF field is shown in Fig.3. Structural map for reservoir pay zones and reference wells location is shown in Fig.4. Due to geological obstructions, all drilled wells in this field are deviated and horizontal wells. Based on the result of the update simulation study and the new geological model, it is recommended to side track the well due South East from the original hole to hit sandstone in higher position. The first objective of the well is to drain the oil accumulated within the sandstone reservoir. It is expected to be penetrated at depths 4000 and 6020 ft TVDSS with vertical thickness 30 ft. Entering sand layers and basement are considered as the second objective and expected to have more than 40 ft cumulative vertical thickness of sandstone.

System	Series	Formation	Member	Lithology	Reservoir Rock	Source Rock	Pay Zone	Thickness	Description
Quat.								170	sandstone
TERTRAY	Moicene	MIDDLE	A					1000	
			B					1800	Gypsum Rock Salt Anhyd. Shale Limestone
								250-2300	
								200	Shale&L.S
			C					1100	Salt Rock
								450-2000	Anhydrate Shale
			D					250	Shale+Anhyd
								500	Shale Lime Sand
								200	Anhyd., Shale Lime Stone
			E						Lime stone Shale
Cretaceous	lower middle upper	LOWER	F						Anhydrate Lime stone Shale
			G				●	+4000	Cherty L.S
			AA-					140'	H.Calc Sand
			BB-					100'	Cherty L.S
			CC-					155'	Anh.Cherty L.S
			DD-					600'	Shale+L.S
			CC-				●	150'-1310'	S.S +Shale
Pre-cambrian		FF-					●	250'-1100'	S.S +Lime Stone Granite Dolerite

Fig.3. Geological column for GOF field.

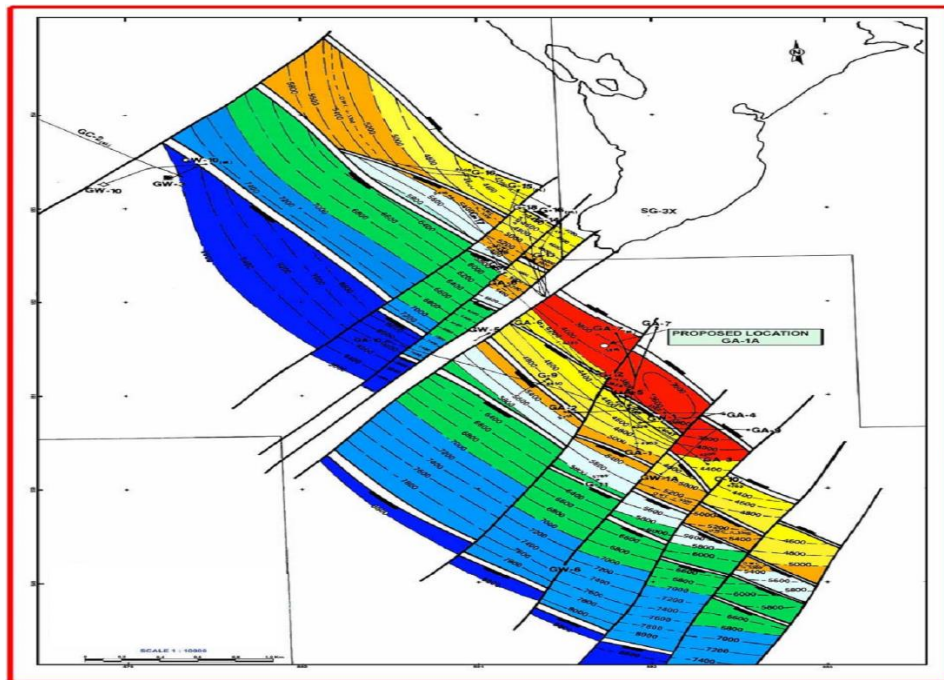


Fig.4. Structural map for reservoir pay zones and reference wells location.

Future development plans

Each company has its own plans for future performance in order to keep its position in the competitive market of the petroleum industry. These future plans are divided into plans of increasing the production and plans of exploring new fields. The present plans for our company is a development strategy. In order to maximize the oil production GOF field reservoir, development wells are, therefore, required to be drilled. There are several wells producing from this field. Two wells, which will be drilled to develop new zones, are called GA-1A and GA-9A. Well objectives include the followings.

- The strategic objectives are:
 - to withdrawal & produce the attic oil existed as up dip of reservoir
 - to prove the oil potential indicated by the dynamic data
 - to locate the undeveloped locations of the incremental potential
 - to drain the undeveloped reserves in the most up dip part towered east direction of the field
- The technical objectives are:
 - no harm to people, environment or property
 - well delivery within planned time
 - evaluating the fluid content and stratigraphy of Upper Cretaceous sands and basement

- providing reservoir data from LWD GR/RES/Neutron / Density logging equipment while drilling and from W/L logging tool including Gamma Ray /Resistivity/DIP METER /MDT/USITCBL/FMI in case Upper cretaceous sand is an oil pay.

Tackling potential drilling hazards

Tackling obstructions of GOF field is a vital way to optimize wellbore trajectory. These obstructions include the followings:

Abnormal Pressure/Saltwater Flow. All pore pressure indicators must be closely monitored and mud weight increased accordingly to maintain sufficient overbalance for safe drilling practices. Rams should be tested to 300 till 3000 psi and annular ram to 1500 psi. All tests should be 10 min/10 min test (which means every test should be 10 min followed by the second one which will last also 10 min. i.e testing the ram with 300 psi lasts 10 min and testing for higher pressure (i.e 600 psi) lasts also 10 min.) using cementing unit and recorded on charts. The IBOP, drilling hose, mud stand pipe should be tested to 5000 psi. All subsequent BOP tests should be carried out on a 3-week basis. The volume of the test fluid pumped shall be monitored and recorded. Depending on the exact FIT at the 9-5/5-in casing window (FIT to 15 ppg) and the mud weight is in use while drilling, the kick tolerance within the 8.5-in interval could be ± 2.0 -ppg. With this in mind, it is imperative that the entire rig crew constantly monitor the well for any abnormal conditions and pit drills should be held on a frequent basis. In addition, no transfer of fluid shall take place over long periods of time. If any fluid is added to the active system, it will be done by incorporating the new pit as part of the active system on all monitoring systems.

Subnormal Pressure/Lost Circulation. The rig site team should be very observant of losses and should monitor drilling practices such as trip speeds, pump rates, etc. in order to minimize the potential for losses. If losses occur, every attempt should be made to heal the loss zone prior to drill ahead (drilling policy states to keep the annulus full with mud, but if there is no more mud, it is advisable to use sea water or diesel according to mud type to keep annulus full). If losses are observed while drilling, losses should be reduced by controlling the drilling conditions and not just decreasing mud flow rate in order to continue drilling ahead.

Mobile Formation - Salt Creep – Reactive Shale. Low salinity water pills should be ready to be pumped around the BHA if salt creep happens. Also drilling these formations with salt saturated mud reduces the sticking tendency (MWT with 12 ppg and CL with 185 Kmg/l). Inhibited water base mud with KCL (7%) will be used to stabilize shale problems during drilling 8.5" hole.

Differential Sticking. Every attempt should be made to minimize the potential for differential sticking. This includes the utilization of spiral drill collars, minimizing the length of the BHA, maintaining a thin, hard filter cake, and keeping the pipe moving at all times possible. If the pipe does become differentially stuck, if possible, immediately the pipe should be landed down with right hand torque in order to free the pipe.

Drill String Washout/Twist off. There are many drill string washout cases in the offset wells, so, the drill pipes and all BHA should be inspected very well before running into the hole. Also, the sand content should be minimized as low as possible, especially during surface hole which drilled into massive loose sand. In order to reduce the sand content, drilling crew and mud engineer need to pay attention to the efficiency of solids control equipment, specially the shakers and de-sanders.

Hydrogen Sulfide. No H_2S recorded in the offset wells, so it is very low probability to have H_2S in this well, reservoir.

Down Hole Tools Reliability. One of the drilling risks expected is the down hole tools reliability particularly Jars, MWD and Motors in the 8.5" and 6" hole section. All precautions should be taken to ensure the tools have passed the QA/QC standards. Quality check will be reviewed by drilling supervisor for quality assurance.

- Drilling equipment, DP, DC, and BHA need to be inspected to DS-1 category - 4.
- All equipment should have inspection certificate on connection and body.
- Company man should check the certificate validity for any equipment.

Incompetent personnel. One of the drilling risks should have good experience hands on the rig and pre-agreed before job.

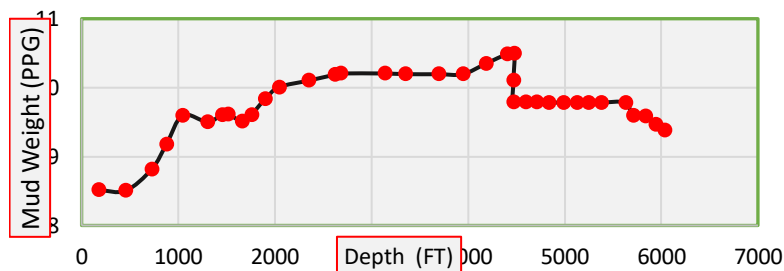


Fig.5. Selected mud weight for well GA-9A.

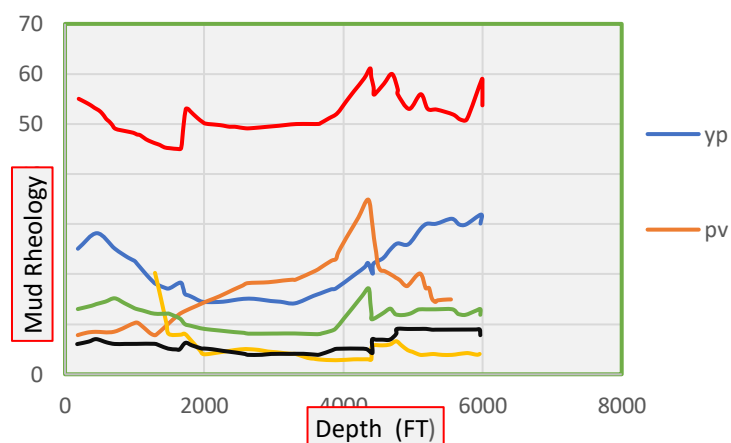


Fig.6. Mud Properties for well GA-9A.

Table 1. Mud Properties for well GA-1A.

Interval	1450-5286 ft MD		6" Hole Interval	5286-5570 ft MDRT	
Fluid properties	Min.	Max	Fluid properties	Min.	Max.
Mud type	WBM	WBM	Mud type	LSND Polymer Mud	
Mud weight (ppg)	11.5	12	Mud weight (ppg)	9.2	9.4
Viscosity (sec/Q)	50	60	Viscosity (cp)	45	50
Plastic Viscosity (cp)	ALAP	ALAP	Plastic Viscosity (cp)	ALAP	ALAP
Yield Point (lb/100ft ²)	20	27	Yield Point (lb/100ft ²)	20	25
6 RPM (Low Shear YP)	8	12	6 RPM (Low Shear YP)	8	10
Zero second Gel	10	15	Zero second Gel	5	10
Ph	9.5	10	Ph	9.5	10
HPHT fluid loss (cc/30min)	8	12	HPHT	-	-
API fluid loss (cc/30min)	4	6	API fluid loss (cc/30min)	5	8
Chloride/CaCl ₂ (k mg/l)	180	190	Chloride/CaCl ₂ (k mg/l)	130	156

Drilling fluids selection

In order to overcome wells GA-1A and GA-9A problems during drilling, the mud density and its properties are determined and plotted in Figs. 5 and 6, and Table 1. The dynamic pressure profile for are estimated from reservoir pressure for well GA-1A as follows:

- basement estimated reservoir pressure and EMW are:
 - initial reservoir pressure = 2240 psi @ 4450 TVDss (EMW=9.5 ppg),
 - estimated current reservoir pressure =1900 psi @ 4450 TVDss (EMW=8.1 ppg),
- sand zone estimated reservoir pressure and EMW :
 - initial reservoir pressure = 2240 psi @ 4450 TVDss (EMW=9.5 ppg),
 - estimated current reservoir pressure=1800 psi @ 4450 TVDss (EMW=7.6 ppg).

For 8 1/2" hole section, The SSM/Polymer WBM will be used to drill this section with the following specifications in order to

- prevent stuck pipe in Evaporite salt,
- inhibit shale reactivity
- minimize/mitigate losses or differential sticking possibilities in sand zones.

Salt saturated water base mud system with weight of 12 ppg will be used in an attempt to obtain sufficient borehole stability to drill, evaluate and quickly case-off these formations. Prior entering shale zone with +/-300', the system will be loaded with 7% KCL. The primary reason for this selection is to ensure approaching maximum well-bore stability while drilling into the most problematic reactive shale of that section. The 6" hole section is composed mainly of granite. API filtrate should

be controlled within a tight value. Hole deviation should not represent any difficulties within 62° inclination. Still, tripping practices must be considered all the time especially within the reservoir intervals. Salt will be the weighting material for this interval to minimize the formation damage. The following mud properties should be used as a guideline for optimizing the mud system while drilling this section.

Selection of the optimum wellbore trajectory

Based on offset wells' analysis, tackling hole problems, wellbore stability and stratigraphic column; the optimum borehole trajectory is selected for two development wells. Well GA-1A will be deviated well while well GA-9A will be horizontal well (Fig.7).

For well GA-1A, the 8 -1/2" hole has been drilled directionally with rotary steerable assembly. The direction work will be achieved while drilling 8-1/2" hole through evaporite formation building angle from 1.72 degrees to 62 degrees and turning to right from 310 to 347 degree azimuth with 3 degree dog leg severity. EOB will be at +/- 3,535 ft MDRT, then A tangent section till the rest of 8-1/2" section. 6" hole section will be drilled maintaining angle and direction to well final total depth. 60' will be drilled into Basement till getting log density neutron recorded 1st foot of basement set 7" liner at ± 5,240 ft MDRT. The Geological target shape is circle with 200' radius. Use Drilling target with 95% confidence. The hole is planned to hold angle at 62° and azimuth at 347° to the section TD of 5,570 ft MDRT. Rotary assembly will be used to clean out 7" liner and drilling Basement formation. A rotary assembly will be used to drill through rest of Basement to TD at 5,570' MDRT (4,000 TVDSS). This section helps to eliminate pipe stationary and to improve the wellbore conditions.

On the second well profile (Well GA-9A), the well is sidetracked due to formation problems and thickness. The horizontal well profile is found be the optimum one to hit target around 90 degrees with 9° /100 ft maximum dogleg severity and 1.03 o/100ft at the total depth (4449 ft TVD, 5975 ft MD).

Recommendations and best drilling practices

In these wells, drilling practices have a lot of impact on the success of the well. The risk of differential sticking, mechanical sticking (Salt creep) is considered high, and all effort must be made to avoid these major NPT events. The following are best practices and guidelines gathered based on offset data analysis to mitigate these risks.

1. Best practices to avoid differential sticking. These guidelines were copied from the hole problem data package manual and textbooks, summarizing best practices to avoid differential sticking.
2. Best practices during drilling include the following.
 - Failure to clean the hole as fast as it is being drilled can cause serious hole problems. Select the hole cleaning to match the maximum instantaneous penetration rate.

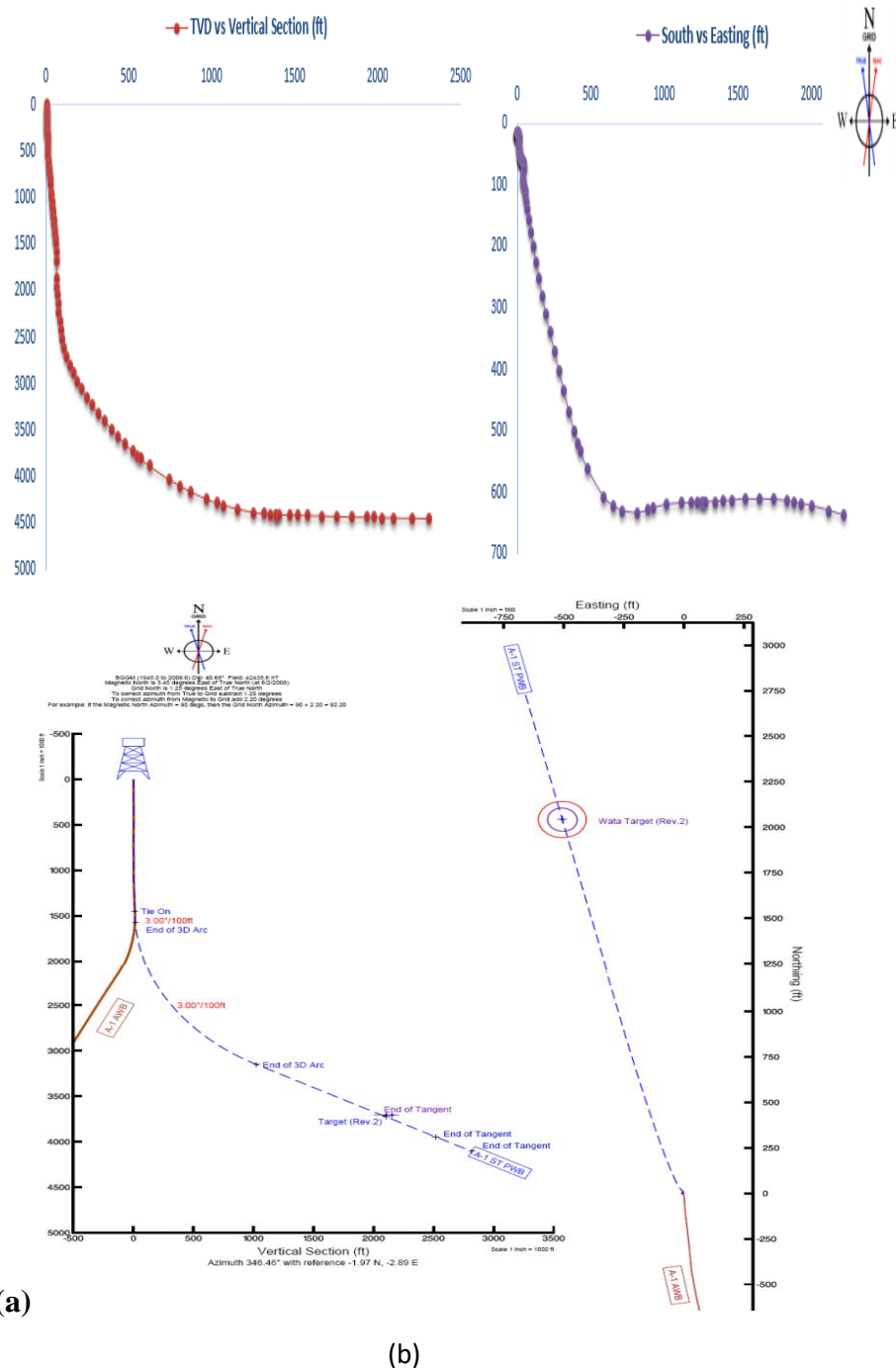


Fig.7. The optimum trajectory (a). Well GA-9A, (b).Well GA-1A

- Monitor the hole constantly for changes in drilling trends. Record the magnitudes and depths of high torques and drags. Always know the bit and stabilizer depths relative to trouble spots. Check the shakers regularly for changes in shape and volume of cuttings.
 - Perform wiper trips as hole conditions dictate. A wiper trip interval can be based on either time or footage (e.g. every 1000 ft drilled, or every 12 hours in mobile formations). Specify a wiper trip interval in any instructions but be prepared to alter this if hole conditions change.
 - Wipe/ream the last single before making a connection in difficult hole conditions (last stand with a top drive). Circulate for as long as possible before a connection. Avoid turning pumps off before picking up. NOTE: The hole may need wiping more often than once per stand with the top drive as fewer connections are made.
 - Wipe the last single or stand before taking a survey. Keep the pipe moving while the survey can wait.
 - When drilling to casing point, a target depth should be calculated based on the casing tally. The rathole below the casing shoe should also be minimized (generally 3-5 ft unless local conditions say otherwise) because the excessive rathole can cause hole cleaning problems, keyseating, and backing off the casing shoe joint.
3. Best practices during hole cleaning are given below:
- Circulate at maximum recommended GPM for hole size.
 - Do not allow the penetration rate to exceed the ability to clean the hole
 - Record torque and drag trends for symptoms of inadequate hole cleaning.
 - Conceder wiper trip after drilling long section.
 - Wipe the hole at full circulation rate as long as possible (5-10min) before connection.
 - Maximize string motion when circulating the hole clean. Use maximum practical RPM (revolutions per minute), raise the drill string slowly (5min/st) and slack-off at a safe but fast rate (1min/st)
 - Consider low vis/high vis sweeps
4. Best practices during tripping are:
- Plan the trip: know where all the potential trouble spots are from drilling and from previous trips.
 - Compare drags/fill volumes with previous trips to monitor hole improvement/deterioration.
 - Ensure trip notes are recorded and handed over at shift change.
 - Know the swab and surge pressures (get these from the mud loggers). Do not exceed the maximum allowable pipe speed when tripping, otherwise well control or formation instability problems may result.

Conclusions

Based on the results and analysis, the following conclusions are extracted:

- GOF offset wells' analysis enhances the performance of new development wells.
- Offset well analysis can identify major problems of GOF stratigraphic column and reduces the non-productive time for future operations.

- Future development plans of GOF field are improved by enhancing drilling well stability and identifying the best hole cleaning practices.
- Drilling fluid selections and their properties help to solve well problems.
- Planned pressure profiles for new wells are exactly determined with the expected zone in which problems appear.
- Borehole trajectory optimization for deviated and horizontal wells are designed based on tackling hole difficulties.

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