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Comprehensive Wellbore Instability Management by Determination of Safe Mud Weight Windows Using Mechanical Earth Model, Meleiha Field, Western Desert, Egypt

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Abstract

Borehole instability while drilling operations in most of formations is a continuing problem that results in substantial annual expenditure for the petroleum industry ($1.3 billion according to some estimates). The technical problems of shale instability are closely associated with majority properties of shales such as, strength and deformation. Other features, like temperature, formation pressure, open wellbore exposure time, interval length of open wellbore, tectonics, etc., can directly impact drilling operations. Drilling a borehole into a formation of different rocks in equilibrium medium makes stress application in the region of the borehole. In circumstances where the stresses significantly exceed the strength the subsequent inequality can cause borehole destabilization. The proposal prospect is located in the southern part of Meleiha Development Lease. The main target of the prospect is to verify the hydrocarbon potential of the Cretaceous sandstone reservoirs, belonging to the Bahariya, and A.E.B. Mbr. The oil and gas bearing reservoir of the A.E.B Mbr. has been proven in some of the wells already drilled within Meleiha Development Lease with some recent successful discoveries in A.E.B. Mbr. A drilling fluid exposure related interaction might occur because parameters such as chemical potential, ionic application, etc., of the drilling fluid and the shale formation fluid are not in equilibrium. Changes in these factors may vary near wellbore formation pressure that will influence the wellbore stress-case and shale state strength and thereby affect the stress-strength balance. An effective drilling process, the interrelated factors, should be included into well planning, mud system selection criteria and/or new mud development. The presented idea here shows the influence of these considerations on wellbore stability. A detailed case study is introduced where methodologies have led to achievements and where the experiences have been transferred into new drilling fluid developments. Results described here are for developing a comprehensive approach borehole instability resolution so helping to deliver better managing of borehole instability issues in the field. The developed model is effective for expecting areas of borehole instability. The mitigation of wellbore instability can be achieved by adjusting the adequate mud weight with the proper selection criteria of the drilling fluid characteristics. However, in some cases, the modification in wellbore trajectory is insufficient and mud weight must be adjusted as well. The developed borehole instability model is potentially applicable to other field cases using a same approach which could be accustomed to the certain field specifications and requirements.

Keywords: Wellbore instability, wellbore stresses, Geomechanics, drilling problems, mud weight, wellbore integrity, wellbore design, rock strength, pore pressure, fracturing gradient, mud design.

1. Introduction

Lack of wellbore stability brings a reduction in the quality of well log records and consequently leads to difficulties in their interpretation so that stability problems are expensive. It also causes mechanical problems such as stuck pipes, high torque and back-reaming, instigating further dangers when setting the casing and removing cuttings. Using a heavier mud can help avoid these incidents, but the range of mud-weight we can apply in such fractured formations is narrow. To solve this, we need to develop methods of

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accurately predicting the important features affecting stability: pore pressure, in-situ stress, shear failure and fracture gradient.

During drilling, stresses are redistributed, as rock is replaced with drilling fluid (mud), which can lead to either shear or tensile failure within a well. If the mud pressure is too low, the stress on the surrounding rock is too great, and shear failure, known as wellbore breakout, occurs, possibly leading to the collapse of the wellbore. On the other hand, if the wellbore mud pressure is too high, there is a danger of tensile failure, causing the wellbore to balloon, and leading to mud loss and lost circulation.

Variations in porosity are also a common feature of fractured formations, particularly carbonates. These lead to rapid changes in pore pressure, and compound the challenges in estimating mud-weights and fracture gradients in drilling. Geomechanics can be used in exploratory wells to predict mud weight windows and predict failures based on offset well data and survey for planned wells. Wellbore instability due to shear failure and tensile fracturing can increase drilling time and sometimes leads to wells being side-tracked or abandoned. It has been estimated that this causes worldwide losses of several billion dollars per year, so it is important to get it right.

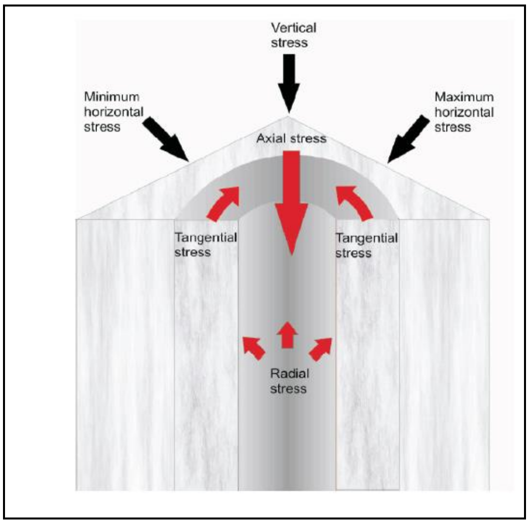

Fig. 1. Wellbore stresses Model: shows Change in near-wellbore stresses caused by drilling a vertical well, by BP, Wellbore Stability Handbook, Dec 2008.

1.1. Geological Discussion

The candidate field is represented at the level of Bahariya Fm. and A.E.B. IIIE by a four way dip closure structure, while the level of Bahariya VI is a three way dip closure structure controlled from the north by a NW-SE dipping fault. The structure setting is based on the 3D seismic interpretation and calibrated by well data. In Meleiha area extensional faulting took place during two main periods: in Late Jurassic-Early Cretaceous and Turonian-Early Tertiary. In between these periods of faulting, subsidence occurred through flexural down warping of the North African margin. Faulting style is predominantly extensional (normal), although oblique slip must have occurred, giving rise to the various trends of existing faults. The degree of such movements may not be significant regionally. Fault movement contributed to subsidence and locally represents the main control during tectonic periods; however regional flexural down warping represents the primary structural mechanism, throughout Mesozoic and Early/Mid Tertiary.

The reservoir characteristics and properties are quite well known from the nearby wells that already penetrated the sequence. The reservoir characteristics from the sedimentological point of view for Bahariya sediments were deposited in a tidal and near shore environment and Alam El Bueib reservoirs were deposited in a fluvial/delta environment, varying from near-shore system to pro-delta settings. The porosity values in Bahariya reservoir range from 14%-25%. Thickness of the sand reservoir range from 3 ft to 41 ft. Alam el Bueib IIIE reservoir porosity range from 13%-17%, while the gross thickness range from 500 ft to 700 ft. The main uncertainties and risks of these reservoirs are related to the lateral continuity and permeability of the sandstone bodies, which could affect the production performance of the reservoir.

1.2. Wellbore Instability Problem Background

At any given time during the drilling process, borehole stability is controlled by the relationship between the near-wellbore stress-state and the rock strength. The first stage of wellbore stability analysis consists of identifying and interpreting the problems observed in the field. Correct identification and classification of the wellbore instability at hand is of utmost importance for any additional analysis.

Wellbore instability observed while drilling can be grouped into five basic types:

1. Washout or hole enlargement
2. Tight hole
3. Formation swelling
4. Lost circulation
5. Differential sticking

The first three types of instability are associated with the near wellbore region; and they are sometimes collectively referred to as near wellbore collapse. In contrast, lost circulation and wellbore breathing are attributed to mud invading the far field as a result of either hydraulically induced tensile fractures or losses occurring to permeable formations or thief zones. Drilling problems and wellbore instability is interrelated. It is important to understand the possible connections, first to diagnose the problem and, second to take appropriate remedial actions.

Fig. 2.Location map of the Study Area, Western Desert, Egypt. (Handbook 2005).

Washout or hole enlargement. While drilling, evidence of washout is given by several observations including excessive cuttings return at surface, excessive hole fill after tripping, mud volumes in excess of calculated amount, oversize hole from LWD calipers, etc. Washouts can be explained primarily by two mechanisms, borehole collapse of a portion of the wellbore due to insufficient mud weight and/or hole erosion due to improper mud chemistry design

Tight hole. This reduces annular clearance and can be observed directly from calipers as under gauge hole. Other indirect observations while drilling are, increased torque and drag, increased swab and surge pressures, stuck pipe and an increase in over pull (hook load) during tripping operations. Although indirect drilling observations can often be associated with other factors such as solids loading that can also reduce annular clearance. Tight hole is expected to show time-dependency for formations prone to creep (e.g., salts).

Formation swelling. This corresponds to near-wellbore zone of shale altered as a result of hydration or swelling. Improperly designed water-based muds can lead to shale hydration or swelling. Main problems associated with sticky hole are increased torque and drag and key seat, especially in high angle holes.

Lost circulation. These can be classified as total losses (lost circulation) or partial losses with some gains (wellbore breathing). In an intact formation, a hydraulic fracture is initiated by too high a mud weight. The high mud pressure causes tensile failure. Following fracture initiation, the fracture may propagate depending on the maximum borehole pressure and take in drilling fluid. When the borehole pressure is reduced the initiated fractures close and may give mud back (often associated with a build-up in annular pressure).

Differential sticking. Due to high differential pressure between the hydrostatic pressure and pore pressure in presence of high permeable zones.

However, in most practical circumstances, the poor definition of key input parameters (i.e., in-situ stresses and rock strengths) justifies at best, a simplistic conservative elastic analysis. In these cases the rock strength is determined by utilizing a peak-strength criterion (e.g., von Mises, Drucker-Prager, Mohr- Coulomb failure criterion).

Once the type and degree of borehole instability has been identified, the next step is to recommend means of improving the situation. Mitigating borehole instability involves changing some of the operational parameters involved, usually mud weight and mud composition. The optimum corrective action depends on a proper assessment of the cause of borehole instability and of the effect of the measures contemplated. The following case study demonstrates the general approach.

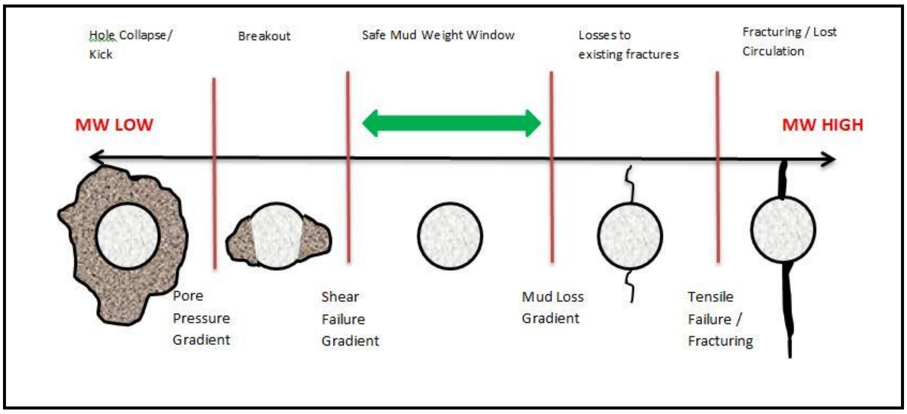

Fig. 3. Effect of mud weight on the stress in wellbore wall.

2. Results and discussions

2.1. Types of Borehole Instability

The borehole instability issues are categorized into borehole instability due to chemical factors and borehole instability due to mechanical factors as shown below in fig.3.

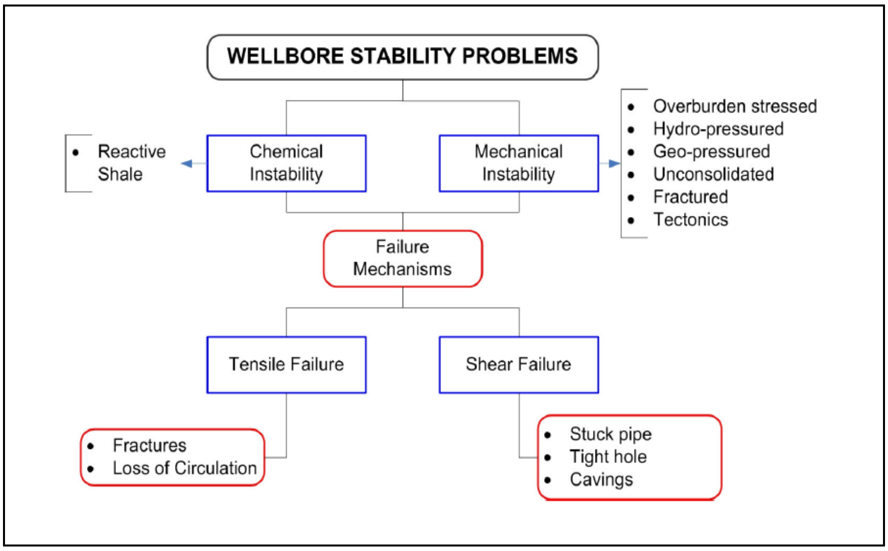

Fig.4. Borehole Instability Problems Classification, by BP, Wellbore Stability Handbook, Dec 2008.

2.2. Borehole Instability Reasons

Instability of borehole is usually because of a mixture of causes which may be broadly classified as being either controllable or uncontrollable (natural) in origin. These reasons are presented in Table 1.

Table 1. Illustrate the reasons of Borehole Instability (McLellan et al., 1994a, Bowes and Procter, 1997; Chen et al., 1998; Mohiuddin et al., 2001).

Uncontrollable (Natural) Causes	Controllable Causes
1. Naturally Fissured or Faulted Strata/ layers	1. Hydrastatic pressure (weight of mud)
2. Tectonically Stressed layers	2. Well Inclination and Azimuth
3. High In-situ Stresses	3. Transient Pore Pressures
4. Mobile Formations	4. Natural and chemical Formation-Fluid Interface
5. Unconsolidated Formations	5. Drill String Vibrations
6. Normally Over-Pressurized Shale Failure	6. Erosion
7. Exposed Over-Pressurized Shale Failure	7. Temperature

2.3. Signs and Marks of wellbore instability

Signs of borehole instability are categorized into direct and indirect signs as shown below in table 2.

Table 2. Displays the Signs of borehole instability.

Direct signs	Indirect signs
1. Oversize hole	1. High friction values for both torque and drag
2. Under gauge hole	2. Run in hole and pull out of hole obstructions for casing string, drilling string, or coiled tubing string
3. Excessive volume of cuttings	3. Abnormal and high circulating pressures
4. Excessive volume of cavings	4. Stuck pipe
5. Cavings at surface	5. Excessive Drilling string shocks
6. Hole fill after tripping	6. Drillstring failure
7. Excess cement volume required	7. Deviation control problems
	8. Difficulties to run casing and wireline logs operations
	9. Poor logging readings
	10. Annular gas seepage because of poor cement bond
	11. Keyhole seating
	12. Excessive doglegs

2.4. Wellbore Instability and Geomechanics

Geomechanics is the discipline that performs identification, analysis and control of rock failure or deformation. This services often referred to as rock mechanics encompass all aspect of drilling and production from well planning, drilling string design and analysis, casing design, drilling operations, open hole logging and perforations design, completions and production design, hence the growing importance of this services in Exploration and Production operations. Wellbore instability is a major problem during the drilling of many oil and gas wells. It is often quoted as costing the industry between 0.5 and 1.0 billion dollars per year.

- **Applications**
- Pore pressure prediction.
- Wellbore-stability forecast and control
- Well planning and trajectory optimization
- Sand production prediction and control
- Reservoir-compaction prediction
- Reservoir stimulation design
- Fracture reservoir characterization
- Drilling risk analysis
- Perforation design
- Earth stress analysis
- Mud weight selection and hole cleaning design

- **Benefits**
- Reduce nonproductive drilling time
- Elimination of unnecessary trips and casing strings
- Reduce rig days by optimal use of operational time, data and resources
- Real-time reservoir management updates for more efficient decisions
- Mud weight selection and hole cleaning design

3. Data Management, Analysis and Approach

3.1. The proposed well is categorized as an exploratory wellbore sited in Western Desert, Egypt. It is targeting possible hydrocarbons in Alam Bueib member, Khatatba Formation. This is a detailed discussion for the recommended drilling and mud programs for each interval based on experience in the field and offset wells data and Geomechanical Earth Model.

3.2. Executive Well Summary

17½” Hole

17½” Hole The 17½” hole upper section will be drilled with conventional Spud mud through Marmarica unconsolidated sands down to top of Moghra formation /- 753’, then the hole will be displaced to Salt KCl Polymer mud to drill Moghra, Dabaa & Appolonia formations down to 2,730’ where the 13⅜” casing will be set.

12¼” Hole

The 12¼” upper part of this section will be drilled with conventional Spud mud through Apollonia & Khoman formations down to top of AR “A” member at 3,833’ where the hole will be displaced to Salt KCl Polymer mud to drill AR A, B, C, D, E, F & G members down to Bahariya, Kharita, Alamein Dolomite, then the well will be displaced to OBM system at 8,415’ to drill AEB formations to 11,000’ section TD where the 9⅝” casing will be set.

8½” Hole

The 8½” interval will be drilled with VERSADRIL OBM mud system through AEB, Masajid, Khatatba, Lower Safa and Ras Qattara formation where the 7" liner will be set at depth 14,878’. The candidate well is located in Egypt, Western Desert region and it is recommended to be drilled as a vertical hole to total depth 14,878 ft MD KB /13,773 ft TVD/ 13,000 ft TVDSSL within Ras Qattara Fm. The estimated operating time is described as shown below in table 3.

Table 3. Displays the predictable operating time for the candidate well.

Operation Sequence	Phase Time (days)	Cum. Time(days)
Drill 17 1/2" Hole to 2,730 ft	5	5
RUN & CMT 13 3/8" CSG, N/U and Test BOP & LOT	3	8
Drill 12 1/4" Hole to 8500 ft	10	18
Drill 12 1/4" Hole to 11000 ft	15	33
Evaluation Logs	3	36
RUN & CMT 9 5/8" CSG at 11,000 ft MD, Test BOP & LOT	4	40
Drill 8 ½” Hole to 14,878 ft	25	65
Final Evaluation Logs	5	70
Completion	5	75
Total Estimated Time		**75**

3.3. Well Objectives

Drilling Strategy Plans

- To accomplish all objectives within HSE standards.
- To drill and complete the well with no LTI’s.
- To achieve all objectives within /- 10% of the approved well AFE.
- To penetrate the reservoir objective’s in 8½” hole size.
- To maintain hole quality in the reservoir to allow the acquisition of high quality petro physical data and reservoir calculation and fluid sampling by using wireline logging and testing tools.
- If successful, to suspend the well for potential future production.

Fluid Strategy Plans

- Provide hole stability.
- Provide stable mud properties under HTHP conditions.
- Provide appropriate well control.
- Apply Stress Cage techniques, if required.
- Ensure minimal losses.
- Produce minimal environmental impact.
- Compatibility with data acquisition requirements.

3.4. Wellbore Instability Challenges Management

The Potential drilling challenges and wellbore instability issues are highlighted to reduce the potential for borehole instability challenges or to avoid possible wellbore instability issues from occurring.

3.5. Lost circulation

Loss of circulation is the unrestrained flow of drilling mud into the wellbore, and then "lost" or the well goes on "losses". Losses can happen when the drilling mud surpasses the formation fracture pressure, resulting in fractures or invasion of the pore space in the formation. There are many situations that can lead to a loss of circulation: formations that are naturally fractured, cavernous in nature, or with high permeability. Improper drilling conditions. Induced fractures resulting from high downhole pressures and medium casing placement at a significant elevation. Lost Circulation Materials (LCM) means additives added into the drilling mud when there are signs of unintended returns or loss of drilling fluid in the formation. The material is generally rubbery or chipped in nature so that it bonds and seals off areas where drilling fluid loss occurs.

The whole inhibition of loss of circulation is not possible, this is due to the existence of fractured formations, cavernous, or highly permeable areas, cannot be avoided if access is to be made to the target area. However, the loss of circulation can be reduced if some precautions are taken, especially those related to the induced fractures. These precautions include:

- Maintaining proper mud weight
- Minimizing annular friction pressure losses during drilling and tripping
- Proper hole cleaning
- Avoiding restrictions in the annular space
- Adjusting the casing to protect upper weaker formations within a transition zone
- Preventive tests; such as Leak Off Test (LOT) also Formation Integrity Test (FIT)
- Shows information about the pore pressure and fracture pressure gradients for better accuracy with log and drill data.

If lost-circulation zones are anticipated, preventive measures should be taken by treating the mud with materials for loss of circulation (LCMs) and protective tests like the leak-off test and formation integrity test should be performed to limit the possibility of loss of circulation.

3.6. Mud weight

The potential risk while drilling the upper section is “loss of return” through the friable loose unconsolidated sands as a result of increasing the mud weight with drill solids consequently exceeding the fracture gradient below the 20” CP, therefore the mud weight will be measured 8.8-9.0 ppg by reducing the concentration of the circulating system with new drilling fluid, improving the shaker screen size and running all available solid control equipment’s.

The primary mud density of NaCl - KCl Polymer mud will be 9.12-9.22 ppg and will controlled to maximum 10.0 ppg at section TD. Controlling the mud weight in this section will be challenging due to the narrow mud weight window between the circulating mud system and the fresh mixed mud, therefore the shaker screen have to be adjusted, and all accessible Solid Control Equipment’s have to be working to control the LGS ALAP.

The proposed drilling parameters showed 10.28 ppg ECD’s with cuttings at the shoe and TD, therefore all precautions should be followed to maintain the ECD’s below the prognosis fracture gradient:

- Maintain proposed mud weight
- Maintain the fluid parameters as per plan, and ensure the hole is cleaned properly
- Optimize ROP (refer to ROP vs. ECD)
- In such big hole size, the friction due to the flow rate is minimum, therefore using high flow rate will enhance the Hole Cleaning condition, and will decrease the ECD and losses risk as well (refer to flow rate vs. ECD).

In case of hole losses, sweep the hole with Pre-Hydrated Bentonite pill (Spud Mud) to put a cake film to the unconsolidated sands, this may be repetitive if any encouraging reaction is observed. If the hole formation losses are not treated, start pumping conventional LCM pill along the loss zone, this may be recurring if any positive response is detected (the pill should be formulated with 40ppb conventional LCM Fine and Medium)

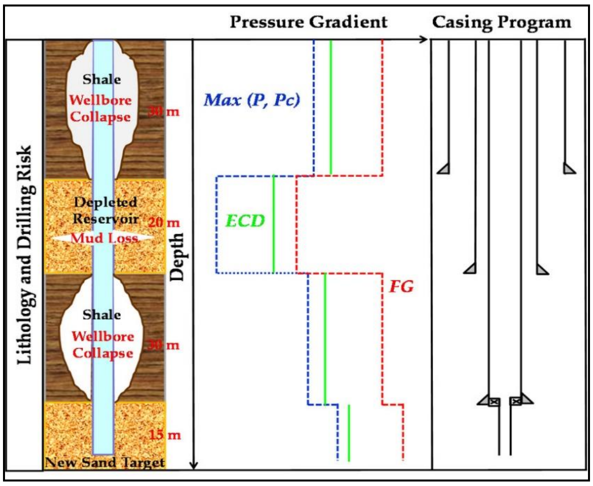

Fig. 5. Schematic diagram for conventional wellbore stability analysis and drilling design

3.7. Hole Cleaning

In such big hole size, it’s very important to maintain the fluid rheology as planned, to achieve good hole cleaning, and to minimize the pack-off and hole losses risks, therefore its recommended to sweep the hole with 50bbls high viscous or Super Sweep pills every one joint (or as detected), in the meantime observing ECD tendency as an symptom of poor hole cleaning.

The proposed drilling parameters showed good Hole Cleaning index, this could be improved by the following:

- Maintain the LSYP as planned (refer to recommended fluid parameters)
- Optimize ROP (refer to HC vs. ROP)
- Maximize the flow rate (refer to HC vs. flow rate)
- Periodic HVP/ Super Sweep pills to ensure the hole is cleaned and no cuttings load in the annulus
- Circulate at the maximum allowable RPM to minimize the cutting load in the annulus
- Monitor ECD, torque and drag for any variation or change in the trend
- At section TD or before any wiper trip, its highly recommended to circulate the hole at least 3 times bottom’s up with maximum flow rate and RPM as the Hole Cleaning index shows fair cleaning, and requires more circulating periods to confirm the hole is properly in good conditions, accordingly no associated tight points though tripping out of the borehole.

3.8. Bit Balling

Bit balling states the linkage of sticky and adhesive clay to the drilling bit, which reduces ROP. Likewise, material can stick to the drilling tolls such as reamers, stabilizers and drill collars, causing deposits of layers and eventually reducing the flow area and possibly promoting swabbing when the bit is pulled. The mechanism where the clay material builds up in layers is referred to “accretion”, which is a compound function of the drilling fluid & inhibition stage, formation classification, bit design & hydraulics, and overbalance pressure.

Therefore, best drilling practices should be applied to minimize the balling risks as follow:

- Maintain the inhibition level as recommended
- Control the LGS ALAP (MBT <15ppb in the KCL Polymer mud system)
- Maintain the planned lubricant and drilling detergent % in the mud system
- Control the fluid loss as planned
- Drilling with maximum allowable flow rate to minimize the cuttings resident time in the annulus
- Drilling with maximum allowable RPM
- Increase hydraulics horsepower at the bit.
- Experience shows that if the Hydraulic Horse Power per square inch (HSI) exceeds 2, bit balling may be prevented.
- Bit nozzle Velocity shouldn’t be less than 250 ft/sec.
- The BHA should be designed with large open face volume / junk slot area.
- Consider adjustments to the nozzle configuration to improve bit cleaning.

If bit balling is experienced, 50 bbls of Spersene pill loaded with 10 ppb Nut Plug Medium should be displaced with maximum allowable rate to eliminate the potential sticky clay around the bottom hole assembly.

3.9. Differential Sticking

As stated earlier, the differential sticking potential in this section is high due to drilling depleted sand, therefore all the precautions should be applied to minimize this risk:

- Use the lowest practical mud weight
- Minimize over balance, and cutting load in the annulus
- Load and maintain the system with bridging materials (if the mud weight window allows)
- Optimize the shaker screen size to maintain the bridging materials in the mud system
- Optimize the shaker screen size to maintain the bridging materials in the mud system
- Control the HTHP as planned to improve the FC quality
- Minimize static period - Keep enough stock of pipe free agent

4. Results and discussions

4.1. Classification of Wellbore Instability

The borehole instability issues are categorized to chemical borehole instability and mechanical borehole instability as shown below in fig.6.

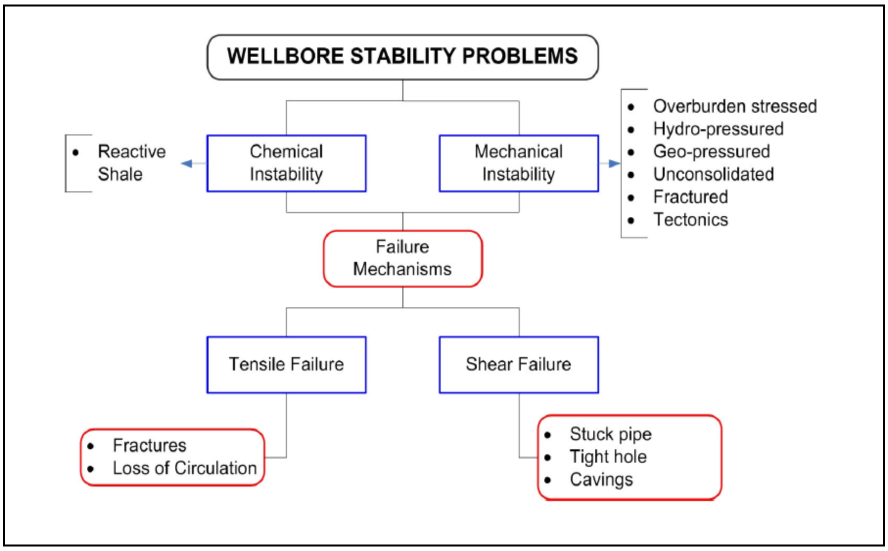

Fig.6. borehole instability Issues classification, by BP, Wellbore Stability Handbook, Dec 2008.1.2.

4.2. Reasons of Borehole Instability

Borehole instability is usually occurs because of a combination of features which may be broadly classified as being either controllable or uncontrollable (natural) in origin. These factors are shown in Table 4.

Table 4. Displays the reasons of Borehole Instability (McLellan et al., 1994a, Bowes and Procter, 1997; Chen et al., 1998; Mohiuddin et al., 2001).

Uncontrollable (Natural) Features	**Controllable Features**
1. Fractured or fissured Formations	1. Downhole Bottom Pressure (Mud Density)
2. High Stressed Layers	2. Well Inclination and Azimuth
3. High In-situ Stresses	3. Transient Pore Pressures
4. Mobile Formations	4. Natural/chemical Interaction of Rock-Fluids
5. Unconsolidated Formations	5. Drill String Vibrations
6. Over-Pressured Clay Failure	6. Erosion
7. Over-Pressured Induced Clay Failure	7. Temperature

4.3. Signs and Marks of Borehole Instability

Borehole instability signs are categorized to direct and indirect signs as shown below in table 5.

Table 5. Displays the Signs and Signs of borehole instability.

Direct indicators	Indirect indicators
1. Oversize hole	1. Increasing torque and drag
2. Under gauge hole	2. Slack of Drilling string, liner casing, or coiled tubing
3. Excessive volume of cuttings	3. High circulation pressures
5. Excessive volume of cavings	4. Stuck pipe
6. Cavings at surface	5. Unnecessary drilling string shocks
7. Hole fill after tripping	6. Drillstring failure
8. Excess cement volume required	7. Deviation control problems
	8. Incapability to run open hole electric logs & Casing
	9. Poor logging readings
	10. Annular leakage gas because of inadequate cement job
	11. Keyhole seating
	12. Excessive doglegs

4.4. Engineering Guidelines

- Check the make-up water before mixing the Bentonite. Pre-hydrate bentonite with the maximum allowable concentration. Mix enough quantity of Spersene CF to coat the Gel mud (if required). Fill half of the tank volume with treated existing water. Transfer the pre-hydrated gel over the treated water pits.
- Contingency chemicals should be available (PipeLax, D-D, Defoamer, Conventional LCM, etc…).
- Polymers must be mixed in low hardness drill water to obtain maximum efficiency. Check the preparation and fix chemistry as necessary in advance of mixing polymers. - Maintain enough LCM materials on the rig site to ensure quick response in case of hole losses.
- Optimize the shaker screen to control the LGS ALAP.
- Run all the available SCE.
- Additional pre-hydrated Bentonite (PHB) viscous sweeps may be required in the upper sand interval to ensure adequate hole cleaning.
- Additionally, high viscosity sweeps should be periodically circulated and observed back on the shale shakers in order to check on hole cleaning efficiency.
- Viscous pills should be also spotted on bottom prior to making trips.
- After the wiper trip and the hole has been circulated clean, a viscous pill of 100 bbls should be spotted on bottom prior to running the casing. The viscosity of the treated sweep should be controlled by Yield Point greater than > 30 lb / 100ft2.
- Maintain MBT in the range of 25 - 30ppb (Spud Mud), and below 10 ppb with NaCl KCl Polymer
- If losses occur, increase the high viscous sweep frequency (Spud Mud), and pump 40 ppb conventional LCM pill across the thief zone which may be repetitive if any response is detected.
- Additional pre-hydrated Bentonite (PHB) viscous sweeps may be required in the upper sand interval to ensure adequate hole cleaning.
- Drilling into the Dabaa safely will require constant dilution of the system with fresh fluid while dumping the sand traps.
- Add conventional LCM pill across the loss zone which may be frequent if any improvement is noticed.
- Insure the utilization of the proper PPE (Personnel Protection Equipment) and HSE

(Health, safety & Environmental) materials. Run daily hydraulics to optimize rheological properties to achieve good hole cleaning.

- HTHP should be run at API conditions; 300°F and 500 psi differential pressure.
- Safe mixing procedure should be applied.
- Insure the utilization of the proper PPE (Personnel Protection Equipment) and HSE (Health, safety & Environmental) materials.
- Fine tune OBM to the recommended specs.
- Dress the shakers with suitable screen to make sure the OBM to avoid LGS build up and maintain the stress cage material.
- It's recommended while displacement to use maximum pump rate, no pumps shutdown to minimize channelling, keep reciprocating and rotating the drill pipe slowly.
- Maintain fluids rheology as programmed, pump HVP as required and monitor for cuttings volume.
- Dilute the system as required to control drilled solids less than 6%.
- Reduce LGS and solids build up as much as possible to maintain the lowest possible ECD while drilling.
- CaCl2 weight % will be maintained as per specs.
- Pipe free agent chemicals will be kept on board, the pill will be mixed in slug pit or batch mixer if required.
- Load system with the suggested recipe of well bore strengthening materials (if required)
- Maintain Lime > 5 ppb

4.5. Recommended Drilling Parameters

Table 6. Illustrate the endorsed drilling parameters for the nominee well

Hole Size	**Bit Jets/ TFA**	**WOB klbs**	**RPM**	**Flow Rate gpm**	**SPP psi**	**ROP ft/h**
17 ½”	4X18/32” TFA: 0.994 in^2	0-20k	100-120	900	2,600-2,700	40
12¼”	4X16/32” TFA: 0.785 in2	0-20k	100	650	2,800-3,000	40
8½”	4X13/32” TFA: 0.629 in2	0-15k	100	425	2,300-2,400	30

4.6. Recommended Drilling Fluid Parameters

Table 7. Shows the endorsed drilling fluid (mud) parameters for the nominee well.

Hole Size (in)	**Mud Weight ppg**	**Viscosity s/qt**	**PV Cp**	**YP lb/100ft^2**	**LSYP lb/100ft2**	**Gels lb/100ft^2**	**FL cc/30min**	**pH**	**MBT ppb**	**Hardness mg/l**
17 ½”	8.8 - 9.1	70 - 80	ALAP	25- 30	> 12	12/17 – 15/22	NC	9 - 10	25 - 30	200 – 400
12¼”	8.8 - 9.1	60 - 80	ALAP	25- 28	> 10	12/15 – 15/20	NC	9 - 10	25 - 30	200 - 400
8 ½”	9.7 - 10.2	50 - 60	ALAP	20-25	> 8	10/15-12/17	4-5 @ 300F	80/20	22%	> 800

4.7. Drilling Fluids Summary

Table 8. Shows the recommended drilling fluid summary for the candidate well.

Interval	Depth ft	Footage Drilled	Mud Type	Mud Weight ppg
20” CP	30 MD	30	-	-
17½” Hole / 13⅜” Casing	30 – 683 MD	653	Spud Mud	8.80 – 9.10
	683 – 2,730 MD	2,047	Salt / KCL / Polymer	9.10 – 10.0
12¼” Hole / 9⅝” Casing	2,730 – 3,833 MD	1,103	Spud Mud	8.80 – 9.10
	3,833 – 8,415 MD	4,582	KCl Polymer	9.20 – 10.0
	8,415 – 11,000 MD	2,585	VersaDril	9.6 – 10.2
8½” Hole / 7” Liner	11,000 – 14,878 MD	3,878	VersaDril	9.7 – 10.2

4.8. Drilling Problems/Mitigations

Table 9. Displays the possible drilling Hazard and the suggested resolutions for each situation.

Risk	**Mitigation**
Hole Losses	- Use lowest acceptable mud weight - Maintain programmed mud properties - Ensure sufficient LCM and mud chemicals on board - Optimize drilling parameters to maintain ECD below the FG
Hole Cleaning	- Run hole cleaning model - Determine required flow rate and rheology - Drilling practices - pipe rotation - Hole conditions on connections - Evaluate effect of increasing rheology / pump rate and controlling ROP - Consider using viscous pill and increase frequency as hole indicate.
Hole instability-chemical Hole instability due to lack of mud weight	- Inhibition is maintained - Optimise mud weight based on offset data and borehole stability modelling. - Consider use of bridging additives
Poor hole cleaning due to low AV in washed out hole	- Maintain gauge hole with correct WPS and MW - Maintain laminar flow. - Identify by increased lag time and cuttings quality
High FLT	- Maintain FLT less than flash point of base fluid (Diesel) - Install mud cooler - Swap active volume with cold mud - Minimize circulation time if not necessarily - Circulate while RIH in stages to cool down the mud
Bit Balling	- Drilling practices - Bit hydraulics - Maintain inhibition - Control WL. - Maintain % Diesel as lubricant - Optimize drilling parameters - Control LGS - Keep enough Nut Plug for dispersant pills chemicals
Differential Sticking	- Control mud weight – minimize overbalance pressure, - Maintain low fluid loss and thin filter cake. - Consider additional bridging materials when drilling sands - Consider a Diesels/Pipe lax Soak pill
LGS increase	- Run finest possible screens that are conducive to effective application of bridging techniques - Optimize SCE - Dump and dilute with fresh mud
HSE	- Training and use the proper PPE - HSE report & STOP card system.

4.9. Geomechanical Earth Model

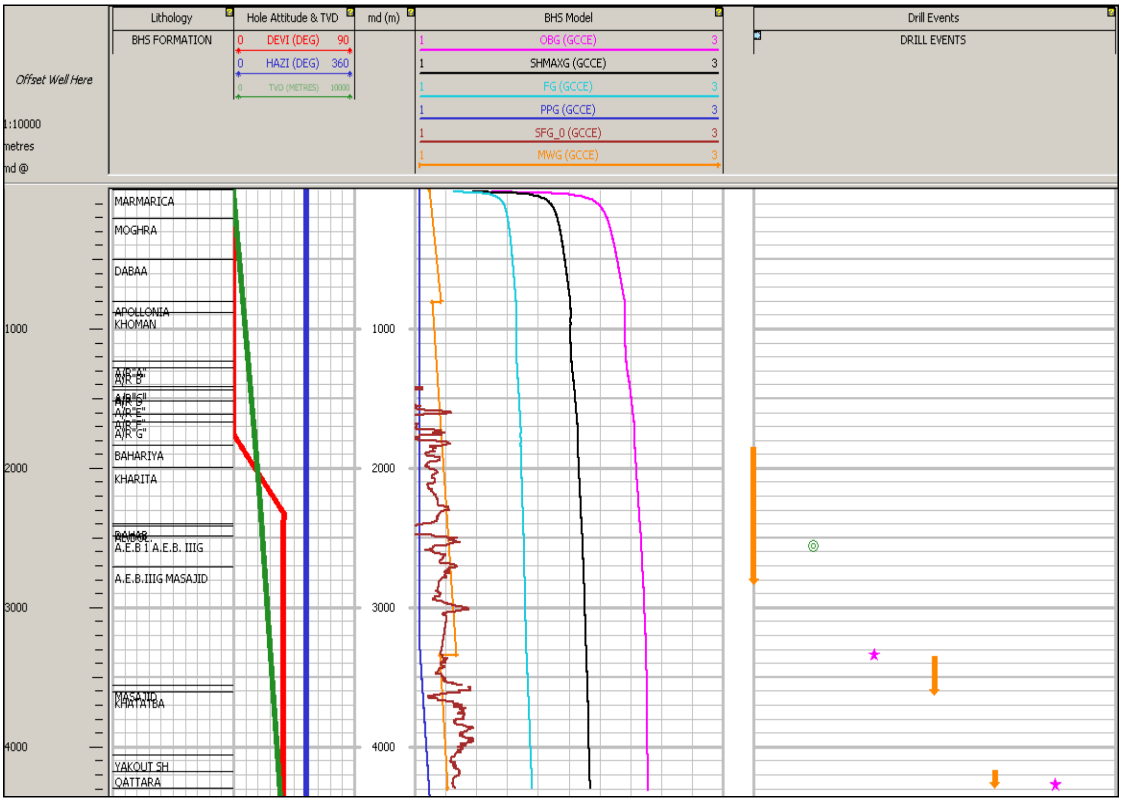

Fig. 7. Geomechanical Earth Model for the Proposed wellbore.

5. Conclusions

Wellbore instability in the candidate field in the Western Desert was influenced by multiple interactive mechanisms which are dominated by the instability of bedding shale and unconsolidated sand zones. Wellbore reduction because of the shear slip alongside the bedding plane in the bedding formation Borehole-instability prevention is the immediate cause for a stuck pipe. An extremely fissured formation and drilling fluid leakage further worsen wellbore instability. For the bedding formation, the drilling fluid will flow into the formation along with the bedding plane, which will lead to a decrease in the bedding plane strength and the active stress on the bedding plane, and this can cause shear failure on the bedding plane. The adverse effect of borehole instability will surge by increasing the borehole open time. Although merely increasing the drilling fluid density is beneficial in retaining wellbore stability for a short time, an increasing in the differential pressure between the drilling fluid pressure and formation pore pressure will aggravate the seepage of the drilling fluid. The long-time exposure of the borehole, increasing the density of drilling fluid will be useless to stop wellbore instability.

Enhancing the sealing specifications of the drilling mud and monitoring the leakage rate based on a proper drilling fluid density is the key to preventing wellbore instability. The borehole instability of the applicant well was assessed, and downhole problems such as pipe stuck and formation losses were effectively avoided in field application. The planned drilling time of the nominee well was decreased by 23% compared with the offset well. Full prevention of wellbore instability is impossible, because of maintaining the physical and chemical in-situ circumstances of the rock is impossible. Nevertheless, the drilling engineer can solve the issues of wellbore instabilities by following the good field practices based on actual events during the drilling operation of the offset wells. These practices include:

- Proper mud-weight selection and maintenance

- Use of proper hydraulics to control the equivalent circulating density (ECD)
- Proper hole-trajectory selection
- Use of borehole fluid compatible with the formation being drilled

Additional field practices that should be followed are:

- Minimizing time spent in open hole
- Using offset-well data (use of the learning curve)
- Monitoring trend changes (torque, circulating pressure, drag, fill-in during tripping)
- Collaborating and sharing information.

The objective of a wellbore stability assessment is to quantify the influence of those parameters that affect the integrity of a candidate well, for example missing bottom hole pressure, formation pressure transmission, hole inclination and others. The analysis of the borehole instability evaluation should be implemented to mitigate the consequences of the instability. A wide variety of analytical and numerical models exist for prediction wellbore stresses and types of instability for nearly all potential conditions, wellbore profile geometries, rock characteristics and borehole fluids. Committed laboratory analysis and in-situ stress evaluations are required to get more assurance in predictions achieved with analytical or numerical modeling tools. Every well should be evaluated individually based on next criteria: the type of anticipated issues, their possible severity, the volume of data and data quality are required for an appropriate analysis, time and budget, and the success of previous analyses of particular type.

List of Abbreviations and Nomenclature

KCl Potassium chloride
TD Total Depth
TVD True vertical Depth
TVDSSL True Vertical Depth Sub Sea Level
FM Formation
AR Abu Roash
AEB Alam El Buieb
KB Kelly Bushing
Ft Foot
CSG Casing
N/U Nippling Up
BOP Blow Out Preventer
LOT leak Off Test
CMT Cement
HSE Health Safety Environment
AFE Authorization For Expenditure
HTHP High Temperature High Pressure
LCM Lost Circulation Materials
FIT Formation Integrity Test
NaCl Sodium Chloride
CP Casing Point
PPG Pound Per Gallon
LGS Low Gravity Solids
ALAP As Low As Possible
ECD Equivalent Circulating Density
ROP Rate Of Penetration
P Pressure
Pc Capillary Pressure
FG Fracture Gradient
M Meter
LSYP Low Shear Yield Point
HC Hole Cleaning
RPM Revolutions Per Minute
MBT Methanol Blue Test
FT/SEC Foot Per Second
BBLS Barrels
SCE Solid Control Equipment
FC Fluid Control
PHB Pre-Hydrated Bentonite
Lb Pound
PPE Personnel Protection Equipment
OBM Oil Based Mud
PPB Pound Per Barrel
TFA Total Flow Area
GPM Gallon Per Minute
PSI Pound Square Inch
KLBS Kilo Pounds
FT/H Foot Per Hour
MG/L Milligram Per Liter
NC No Control
F Fahrenheit
PV Plastic Viscosity
YP Yield Point
IN Inch
MD Measured Depth
WL Water Loss

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