Republic of Yemen
Ministry of Higher Education and Scientific Research
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Faculty of Engineering and Information Technology
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Student Affairs System

Emirates International University

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Impact of wellbore instability on the drilling performance in Say'un- Masilah Basin (Block 53 – Sharyoof Field).

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Submitted in partial fulfillment of the requirements

for the award of Bachelor degree of the

Oil and Gas Engineering

DECLARATION

We hereby declare that this Bachelor's Project is the result of our own work, except for quotations and summaries which have been duly acknowledged.

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APPROVAL

This is to certify that the project titled **Impact of wellbore instability on the drilling performance in Sayun-Masilah Basin (Block 53 – Sharyoof Field)**. has been read and approved for meeting part of the requirements and regulations governing the award the degree of Bachelor Engineering in Oil and Gas of Emirates International University, Sana'a, Yemen.

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ABSTRACT

Drilling operation considered as the most important procedure of oil field operation. This importance came out not just from its risks and danger but also from its economic considerations which had bad effects due to non-productive time that may losses. Wellbore instability considered as the worse problem that the engineers faced. During drilling operations for the **Sharyoof** oilfield at **Block-53** in Sayun-Masilah Basin in the East part of Yemen, Wellbore instability has been identified in Harshiyat formation that compose of "Sandstone, Claystone and Siltstone" as a significant Geomechanical problem for several wells that started as fluid lost circulation aggravated to tight spots, pipe sticking which finally ended with changing on planned well schematic with new sidetracks. In this Project, four wells **A, B, C** and **D** have been taken to analyze its instability by using the qualitative, quantitative, analytical and descriptive research approach. The problem has been analyzed and identified based on Mud Program, drilling parameters and wells design for four wells, after analysis process for these data, the resulted of this study is that the problem was due to both mechanical and chemical factors where those wells characterized by inappropriate design for section **$12^{1/4}$"** where it considered as too long section "**1800 m**" through **Harshiyat formation**, **Qishn** (Carbonate and Clastic), **Saar formation**, **Naifa formation**, **Madbi formation**, **Shuqra formation**, **Kuhlan formation** and **Top Basement**. This high length allows the formation to be saturated more by drilling fluids. It had considered that three wells of these four had drilled with inappropriate mud system and drilling procedures. This project concludes solution for this problem which can be summarized with changing drilling schematic that reduce section **$12^{1/4}$"** to start from **Harshiyat formation** and ended at **top Saar formation** and changing the mud system to be the same that used at well D. Tripping procedures should be controlled as additional recommendation.

ACKNOWLEDGMENTS

First of all, we owe our most sincere gratitude to Allah the almighty and the most powerful for offering us such a strength, endurance, willingness, and capability to accomplish this project.

We would also like to express our deep and sincere gratitude to our supervisor, **Prof. Ibrahim Farea**, for his valuable and constructive suggestions during the planning and development of this research work and his wide knowledge and his logical way of thinking that have been of great value for us. His willingness to give his time so generously has been very much appreciated. His feedback, support, encouraging, patience and personal guidance have provided a good basis for the present project.

Our special gratitude is due to all those who have helped in carrying out the research and contributed in any way for the success of this Project.

Finally, yet importantly, we would like to express our heartfelt thanks to our beloved family for their blessings, our friends/classmates for their help and wishes for the successful completion of this project.

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ACP	Abandoned Cement Plug
API	American Petroleum Institute
BBL	Barrel
BHA	Bottom Hole Assembly
BOP	Blow Out Preventer
BOPD	Barrels Oil Per Day
BOPD	Barrels Of Oil Per Day
BSW	Barrels (Of) Salt Water
CP	Conductor Pipe
CS	Casing Shoe
CSG	Casing
DOC	Drill Out Cement
DP	Drill Pipe
ECD	Equivalent Circulating Density
FT	Foot (Or) Feet
GR	Gamma Ray
GS	Gel Strength
HP	Hydrostatic Pressure
HR	Hour
HS	Hole Size
HWDP	Heavy Weight Drill Pipe
ID	Internal Diameter
ID	Inside Diameter
IH	In Hole
KB	Kelly Bushing
KM (S)	Kilometer (Or) Kilometers
LC	Lost Circulation
LCM	Lost Circulation Material
LD	Logger Depth In M/RT
LOT	Leak Off Test (Fit/Lot)
LT	Lost Time
LWD	Logging While Drilling
M/H	Meter Per Hour
MD	Measured Depth
MI	Move In
MIRT	Move In Rotary Tools
MO	Moving Out
MW	Mud Weight
OD	Outside Diameter
OH	Open Hole (Or) Out Of Hole

TD	Total Depth
TOC	Top Of Cement
TOOH	Trip Out Of Hole
TVD	Total Vertical Depth
VOL	Volume
WL	Water Loss, West Line

CHAPTER ONE

1. INTRODUCTION

1.1. Introduction

Drilling operation is considered as the riskiest stage of petroleum industry wherefore, engineers are facing many problems. Some of these can be controlled, but others can be disastrous. This project will discuss one of the problem which can be minimized and avoided. Wellbore instability problem happened during drilling operations which may cause other problems and economic and time losses. The study is about Sharyoof field –Block 53 at Say'un-Masilah Basin. The first chapter will discuss the researcher main goals and overview about the study area.

1.2. Aims and Objectives

1.2.1. Aims

The following are the main aims of conducting this study:

- Analysis of borehole instability causes that impacts on the drilling performance, and find out the methods applying to avoid this problem.

1.2.2. Objectives

To achieve the aims of this study, the following objectives have been defined:

1. Investigate the effect of mechanical stress related to geological structure on the hole instability.
2. Determine the causes of borehole instability problems in Say'un-Masilah Basin.
3. Identify the drilling parameters such as "drilling fluids types & properties, and well design".
4. Find out recommendations to prevent borehole instability during drilling operations in Say'un-Masilah Basin.

1.3. Problem Statement

Wellbore instability considered as one of the main problems faced the engineers during drilling process. This problem has negative effects on drilling performance and cause losses on time also increasing on drilling cost. Other feedbacks occur due to this problem such as drill pipe stacking. This project will focus on studying the causes of this problem on the study area and the implementation to reduce its occurrence or avoid it to happen.

1.4. Research Question

What is the wellbore instability causes that impacts on drilling performance and how to prevent the drilling process from this problem?

1.5. Significant of The Research

Study the impact of borehole instability on the drilling performance is critical for the economic considerations because it has direct impact on planned drilling time. This analysis will focus on identifying the main solutions that will avoid this problem.

1.6. Scope of The Research

Sharyoof field –Block 53 is the scope of this research. Four wells were taken under consideration.

1.7. Say'un-Masilah Basin

1.7.1. Geological setting

As with most other oil-bearing basins in eastern and western Yemen, the Masilah Basin initiated as a rift basin during Upper Jurassic-Early Cretaceous post-Pangea breakup. Rifting caused a series of northwest southeast and west-east trending major basin-bounding faults evolving, adjacent to which are three main Jurassic-Cretaceous rift graven basins of Yemen: The Marib-Shabowah, the Masilah, and the Jiza'-Qamar Basins (**Fig. 1-1**). The tectonic evolution of the Masilah Basin can be divided into three stages: pre-rift, syn-rift and post-rift (**Fig. 1-2**). Pre-rift megasequence ranges in age from Proterozoic to early Late Jurassic. The Pre-rift has been penetrated by wells drilled in the Masilah Basin.

1.7.2. Stratigraphy Of Say'un-Masilah Basin [1]

Basement

The basement of the Masilah Basin consists mostly of igneous and metamorphic complex rocks of Proterozoic to early Cambrian age. This basement complex is overlain unconformably by a Jurassic sequence.

Kuhlan Formation

In Early to Mid-Jurassic time, sandstone was deposited widely across Yemen, where thick sedimentation developed in lows formed before Jurassic time. This thick sandstone deposit is known as the Kuhlan Formation, and it is composed of siltstone and sandstone ranging to conglomerate with some streaks of limestone and green clay.

In Masilah Basin oilfields, the sandstone of the Kuhlan Formation is very fine to medium grained, well sorted, and possess of poor to good porosity.

Shuqra Formation

After deposition of the Kuhlan Formation, another marine transgression from the southeast reworked the sandstone and deposited shallow-marine carbonates (Shuqra Formation). The Shuqra Formation is Middle to Late Jurassic in age and consists predominantly of platform carbonate.

Madbi Formation

During the syn-rift sequence, horsts and nested fault blocks were developed, where differential compaction and drape anticlines occurred in the Upper Jurassic to Lower Cretaceous due to basement high. Upper Jurassic sediments, known as the Madbi Formation, were penetrated by wells drilled in the basin. This formation is generally composed of porous limegrainstone to argillaceous lime mudstone. The lithofacies of this unit reflects an open marine environment. This formation is divided into two members. The lower part of this formation is commonly argillaceous lime and basal sand, and forms a good reservoir in some oil fields of the Masilah Basin. The upper member is called Madbi shale and is composed of laminated organic-rich shale and mudstone. The thickness of Madbi shale is 30-100 m.

Naifa Formation

During latest Jurassic to Early Cretaceous time, the rifting in the Masilah Basin continued, but the subsidence became slower. It was accompanied by the accumulation of carbonates as shallow-marine shelf deposits which constitute the Naifa Formation. The Naifa Formation consists mainly of silty and dolomitic limestone and lime mudstone with wackestone.

Saar Formation

The upper part of this formation is composed of very porous clastic carbonate overlain by the Saar dolomite facies. In Early Cretaceous time, sea level rose on relatively flat ground, resulting in marine transgression and sedimentation of widespread shallow-marine carbonate Saar Formation.

The Saar Formation is composed mainly of limestone, dolomitic limestone with some mudstone, and sandstone. Oil companies classified this formation into lower Saar carbonate and upper Saar clastic.

Qishn Formation

The Post-rift megasequence range in age from late Early Cretaceous to Tertiary time and rests unconformably on the syn-rift section. Late Early Cretaceous sediments, known as the Qishn Formation, consist of braided plain to fluvial and shallow-marine sediments deposited in the Masilah Basin. The Qishn Formation is divided into two members, Upper Qishn Carbonate and Lower Qishn Clastic Members. The Upper Qishn Carbonate Member consists of laminated to burrowed lime mudstone and wackestone interbedded with terrigenous mudstone and black fissile shales. These sediments were deposited in deep water under alternating open and closed marine conditions. The Upper Qishn Carbonate Member is a regional seal rock in the Masilah Basin. The Qishn Clastic Member is composed mainly of sandstones, with shale and minor carbonate interbeds, deposited in braided river channels, and in shore face and shallow-marine settings.

Biyadh Formation

The Qishn Clastics Member is also referred to as the Biyadh Formation, in comparison to the Biyadh Sandstone in Saudi Arabia and correlates with the Zubair Formation in the Kuwait and Iraq.

Harshiyat Formation and Fartaq Formation

During the late Early Cretaceous, alternating regression and transgression occurred. This pattern deposited clastic (Harshiyat Formation) and carbonate rocks (Fartaq Formation) interbedded with each other.

Mukulla Formation and Sharwayn Formation

A similar pattern of sedimentation occurred in Upper Cretaceous time, where fluvial systems (Mukulla Formation) prograded southeast ward in the Masilah Basin. The Late Cretaceous Sharwayn Formation deposits are composed mainly of shale.

Umm Er-Radhuma Formation

The overlying Tertiary units comprise homogeneous argillaceous, detritus carbonates and hard, compacted, massive and bedded dolomitized fossiliferous limestone with local chert nodules (Umm Er-Radhuma Formation) that changes to shales with minor limestone bands in the upper levels (Jiza' Formation). Jiza'-deposits are widespread in the Early Eocene followed by the deposition of anhydrite beds (Rus Formation).

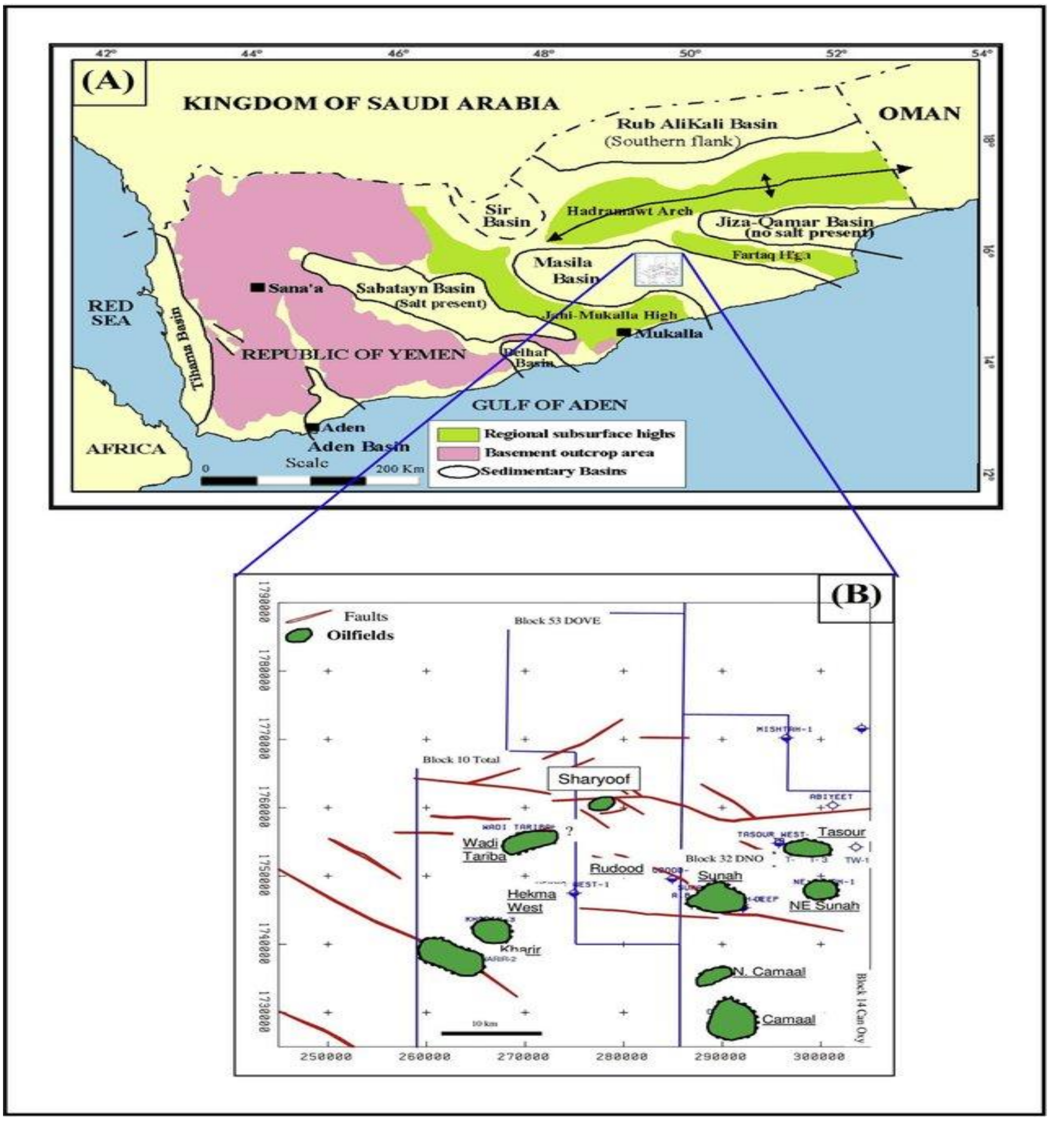

Figure 1-1 Main sedimentary basins in Republic of Yemen showing location map of the oilfields in the Masilah Basin.

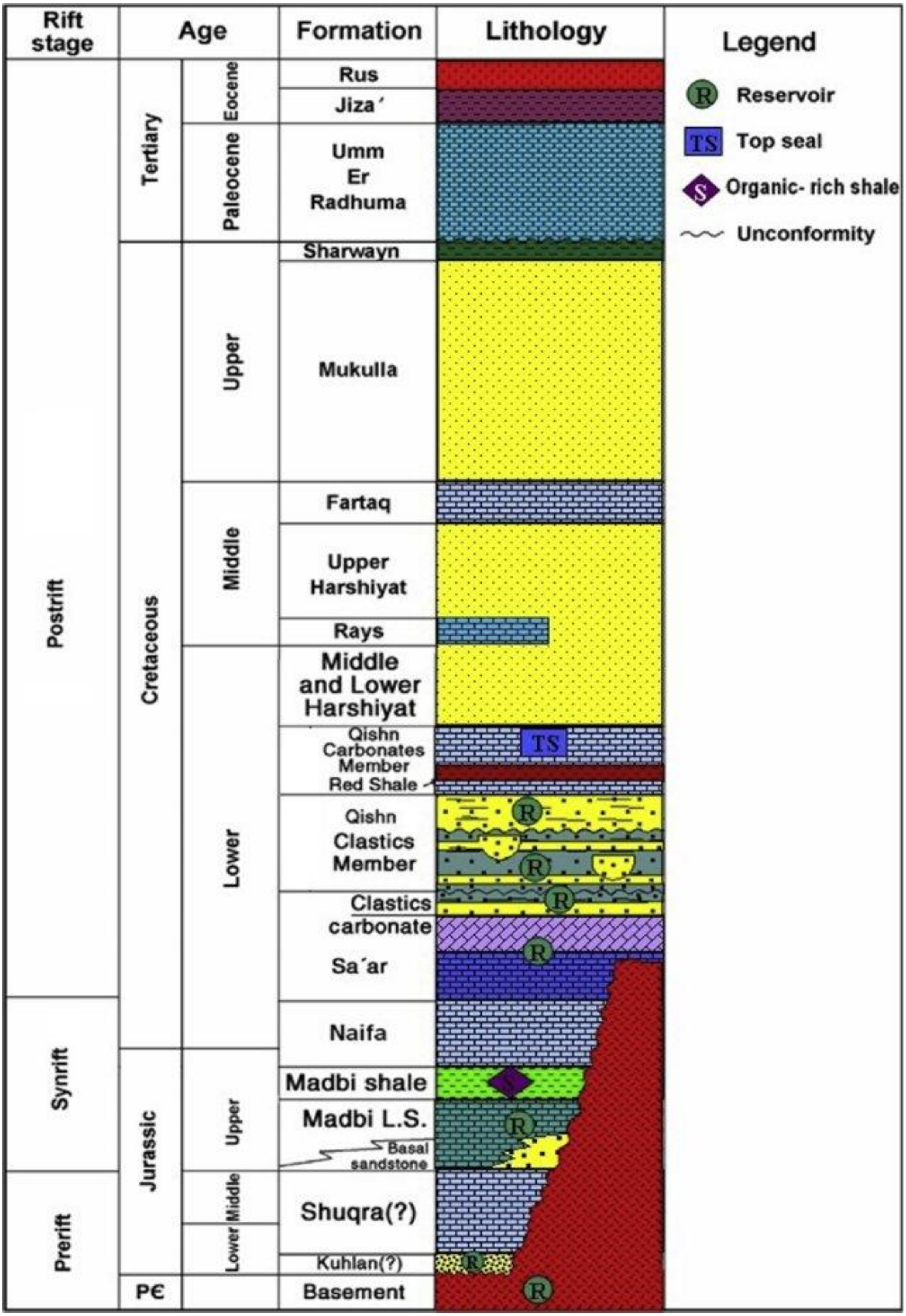

Figure 1-2 Regional stratigraphic nomenclature, Masilah Basin, Republic of Yemen

1.8. Block -53 Overview

Located in the N/W sector from the of Masilah- Say'un basin, with area of 474 Km2. Block (53) is operated by DOVE Energy- British Company [1]. The main reservoirs in the block are (Qishn Clastic), (Saar Sand, Saar Carbonate), and expected to be produce from the fracture basement rocks in the future. The partners in the Production Sharing Agreement with the Yemeni government are:

- DNO (24.45%)
- Dove Energy (24.45%)
- MOE (16.10%)
- PETOIL (10%)
- YCO (25%).

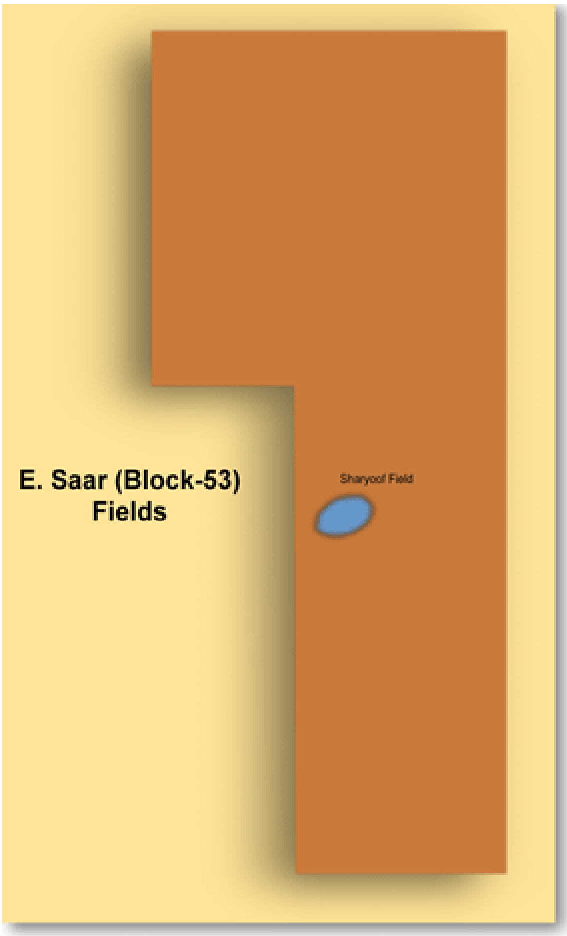

Figure 1-3 Block - 53 Sharyoof Field

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

The Literature review is one of the main phases in performing any research, as it usually highlights the main gaps in the previous studies, which may need to be filled. It helps also to understand the necessary direction to follow to develop the study.

2.2. Geology

This part will examine geology as it relates to drilling operations. It is necessary to understand something about the physical and chemical characteristics of rocks in order to understand drilling processes and problems. The part also describes the basic principles of hydrostatic pressure exerted by a fluid at depth, as this is important for drilling operations.**[2]**

2.2.1. Origins of Rock

When the earth first formed, it consisted of molten rock. As the surface of the planet cooled down, the planet surface solidified. Rocks formed by molten rock cooling and solidifying are called igneous rocks. Basalt and granite are examples of igneous rock (***Fig. 2-1***).

Water and gases form the oceans and atmosphere. The gravitational pull of the sun and moon and solar heating cause movements of the atmosphere (weather) and the oceans (tides and currents). The movements of air, water, and ice erode rocks, releasing rock particles. These effects are called weathering.

Particles of rock, from tiny grains to huge boulders, can be carried long distances by wind and water. Eventually the forces carrying the rock particles are reduced, and the rock fragments fall to the earth's surface, or to the bottom of a water body, forming thick beds of material called sediments. As the water or wind slows down, the largest fragments are deposited first. Smaller fragments (being more easily carried) would move further. In this way, the rock fragments could become sorted so that a particular bed of sediment might consist of fragments all of a similar size. Large particles are deposited in high-energy environments (e.g., a fast-flowing river), and small particles are deposited in low-energy environments (e.g., a lake or swamp).

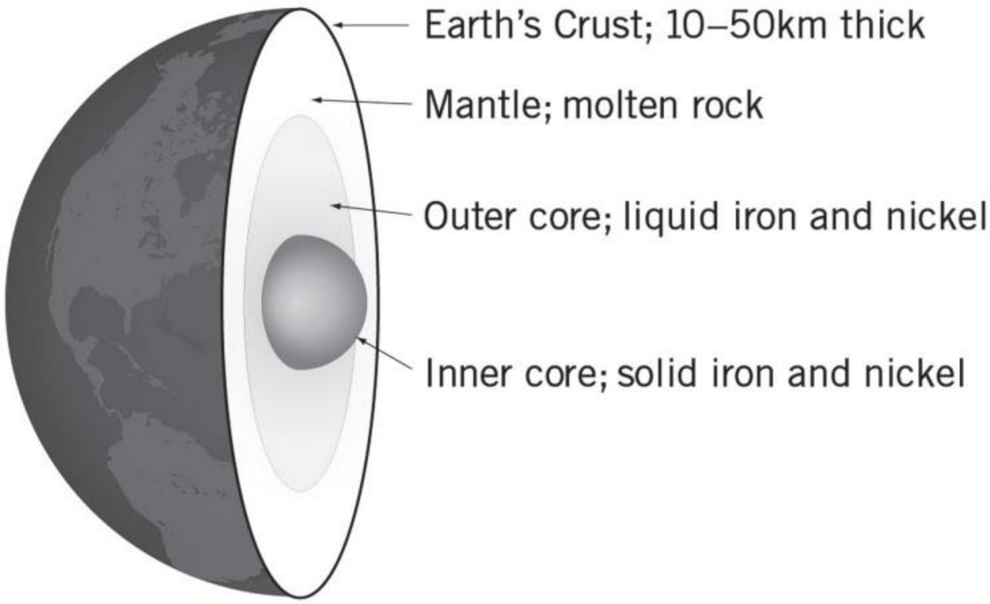

Figure 2-1 Earth's Structure

Over millions of years, these sediments became buried deep within the earth, subjected to high pressures (from the weight of rock above them) and temperatures (the earth gets hotter at increasing depths). The minerals in the sediments change chemically, forming rock. This process of forming new rock by chemical changes to sediments is called *diagenesis*. Other types of rock form by small grains of mineral becoming bonded together by minerals growing where the grains touch, such as sandstone. This process is called *cementation*.

Rocks that are formed by the diagenesis or cementation of sediments are called sedimentary rocks. Sandstone is one type of *sedimentary* rock.

Existing rocks of any type can be physically changed by high pressures and temperatures. This process is called metamorphosis (the same word that applies to a caterpillar changing to a butterfly). These changed rocks are called *metamorphic* rocks.

The rock cycle diagram (***Fig. 2-2***) was first constructed by Scottish geologist James Hutton in a book published in 1795, The Theory of the Earth, with Proofs and Illustrations. Starting at the bottom of the diagram (the square marked as "Magma" or molten rock), move clockwise and upwards around the cycle. Magma cools and solidifies, creating igneous rock. These rocks may be changed into metamorphic rock (branch going to the right) or, continuing around the cycle, may eventually reach the surface and are eroded.

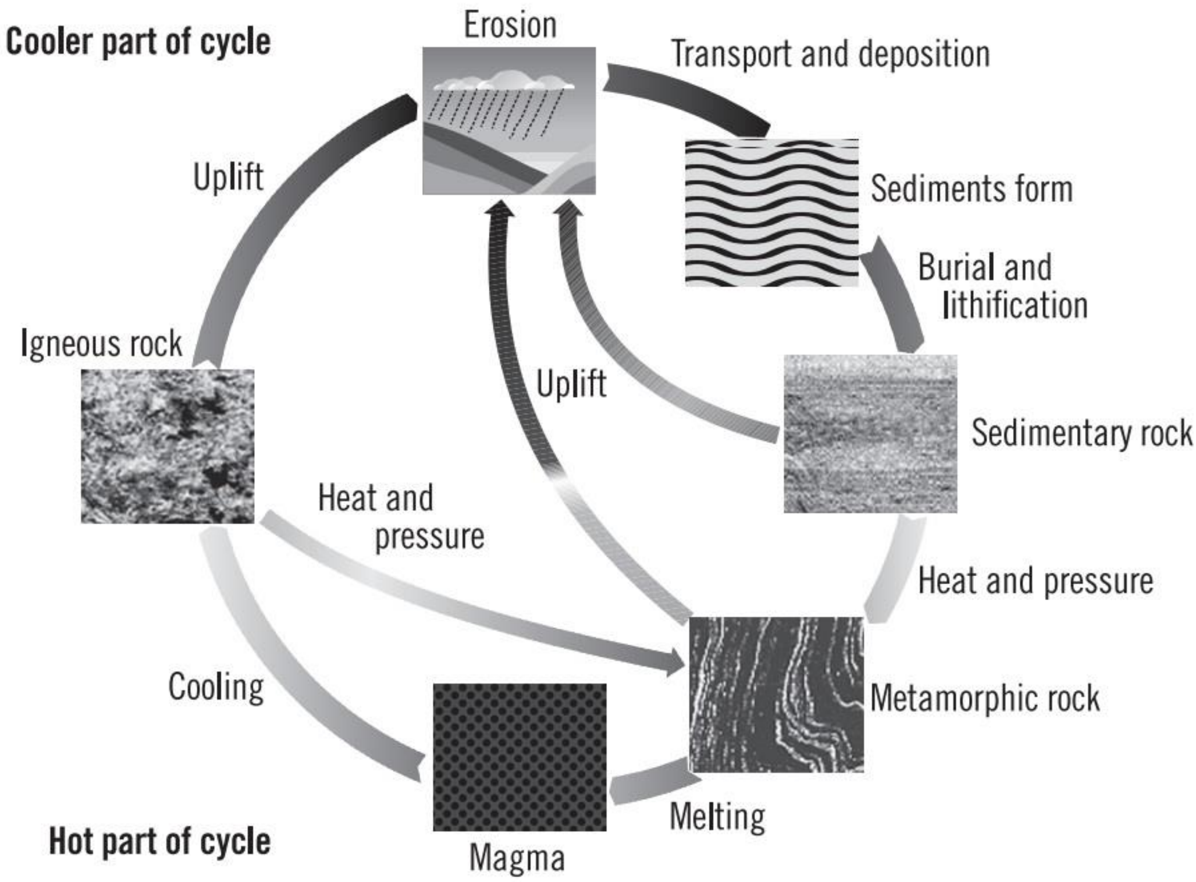

Figure 2-2 The Rock Cycle

The rock particles released by erosion (weathering) are transported by wind, ice, or water. These are deposited to form sediments, which become converted to sedimentary rock (now at the right-hand side of the cycle). From here, the sedimentary rock could be eroded again, or buried deeper. If buried at sufficient depth, the pressure and temperature will metamorphose the sedimentary rock.

Metamorphic rock can be uplifted and eroded, or buried deeper and melted.

Apart from these “physical” sediments, chemical sediments also occur. Salt beds formed from the drying of salty lakes can be very thick and cause some real problems not only for drillers but also for seismic surveying. Biological sediments (such as fossilized coral reefs and coal) are also significant.

In most areas of the world, sedimentary rocks have been deposited on top of basement rocks (igneous and metamorphic). The layer of sedimentary rock above the basement rocks can vary in thickness from zero (eastern Canada) to 50,000 ft or 15,000 m. Around volcanoes, igneous and metamorphic rock may be found at or near the surface, with sedimentary rock underneath.

2.2.2. Plate Tectonics

Below the thin, solid crust at the earth's surface, the planet core is molten. This liquid rock may be seen at the surface in active volcanoes. On top of the liquid rock, the crust consists of plates of solid rock, floating on the molten rock underneath rather like rafts floating on water.

The earth's crust is divided into seven major plates (African, Pacific, Indian-Australian, North and South American, Eurasian, and Antarctic) and numerous smaller plates (such as the Arabian and Cocos). The plates are all moving relative to one another. Some plates are moving apart from each other (e.g., North Atlantic and Southern Indian Ocean), and new crust is formed as molten rock is exposed and cools down. Some are converging (e.g., at the western rim of the Pacific plate), where one plate slides underneath the other, and volcanoes and mountains may be formed. Others are sliding past one another (e.g., western coastal United States at the boundary of the North American and Pacific plates). The rate of movement varies from 1.3 to 17.2 cm/year.

In areas close to the edge of a plate (tectonically active areas), the rocks are under much greater stresses than normal. This can make it difficult to drill a hole that remains stable. The sides of an unstable wellbore will tend to collapse into the hole, enlarging the hole.

Movements of the plates will lead to rocks moving up or down within the earth's crust. It will also lead to rock beds becoming folded, broken, and turned over. Pressures of fluids contained within the rocks can be drastically changed from the surrounding rock. Stresses within the rock may become different in different directions. All of these different stresses can deform and break the rock layers in different ways.

Fig. 2-3 shows what happens when rock is compressed from the sides until the force exceeds the rock strength. Faults (breaks in the rock layers) develop, and part of the rock is pushed upwards. If a well is drilled across a thrust fault, part of the rock sequence will be repeated in the well. If the rock layers' stretch, the opposite happens—normal faults develop. A well drilled through a normal fault will have part of the rock sequence missing (***Fig. 2-4***).

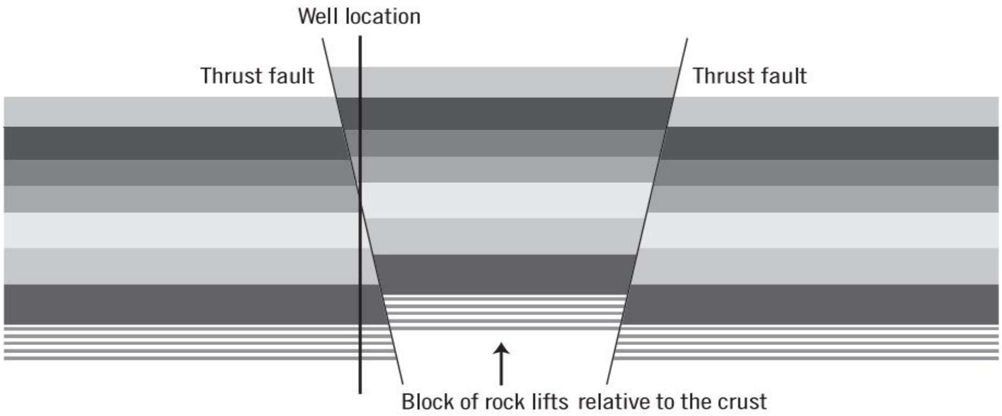

Figure 2-3 Thrust fault, rocks were compressed together

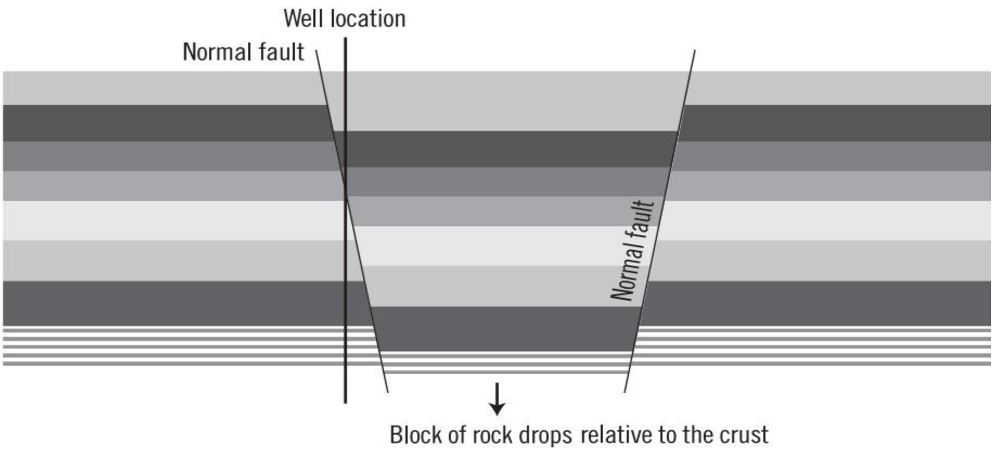

Figure 2-4 Normal fault, rocks were stretched apart

Sometimes the surface rocks are eroded away, and then more sediments are deposited. This is called an unconformity; part of the geological sequence is missing entirely. The photo in ***Fig. 2-5*** shows an unconformity, visible in a cliff face. The white line marks the unconformity surface.

This photo tells an interesting story. Sediments were deposited at the surface or seabed. These became buried, changed into rock, and then were uplifted back to the surface. During this burial and uplift, the rocks became tilted. Now surface erosion removed rock but at an angle to the bedding planes of the rock. Notice the angle between the lower rock beds and the white line of the unconformity surface, which would have been horizontal. Now new sediments were deposited, buried, became rock, and then were uplifted back to the surface and tilted in the opposite direction of the original tilt, but by a lesser amount. The lower rocks have had two return trips down into the earth's crust and have been tilted one way on one trip and the opposite way on the second.

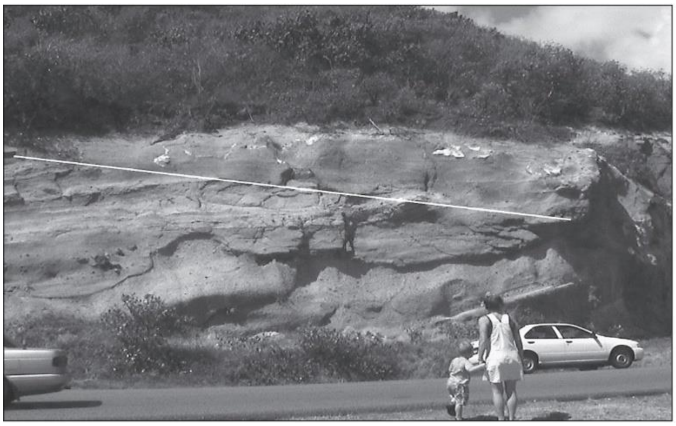

Figure 2-5 Unconformity surface shown by the white line

2.2.3. Lithology

Lithology refers to the physical character of the rock. Lithology is a description of the rock and is based on such characteristics as mineral composition, color, grain size, and other textures. Thus a shale could contain some sand (sandy shale) or a rock could be mainly sand with some shale minerals within it (shaly sand). The lithology will affect many drilling decisions when planning and drilling the well. If the wrong decisions are made due to a lack of detailed lithology knowledge, serious problems can result that will increase the cost of the well and could even prevent the well from reaching its objectives.

2.2.4. Shales

Shales consist of layers of clay minerals. Clay minerals are crystal structures of various metal oxides associated with alumina silicates in connection with varying numbers of water molecules. The metal oxides are most commonly those of iron and magnesium but may also be those of sodium, potassium, or other metals. Their presence together in varying ratios results in a wide range of clay mineral types. Clay minerals originate in sedimentary rocks by the physical and chemical breakdown of other minerals originally present. The weathered clays are carried by wind or water, or both, to an area of eventual deposition. They may then undergo further physical or chemical breakdown. More water may become associated with the clay minerals.

Eventually the clay minerals become buried under other sediments. They will be compacted, and water will be driven off. Diagenesis will alter their structure or composition to change the accumulation of clay minerals into a sedimentary rock type. The water that comes out of the shale is less saline (contains less salt) than the water left behind, so the shale gets saltier as it dehydrates.

Some shales react very quickly with water. Hydration of these shales leads to the crystalline layers expanding. During drilling, fluids are pumped down the hollow drill string and back up the hole to clean and cool the drill bit and perform various other functions. If such a shale is drilled using water as the circulating fluid, the shales can absorb water and rehydrate. Millions of years of diagenesis can be reversed in under an hour.

These shales will swell and become soft, like unset putty. Sticky clays will fill the hole, and if the drill string becomes stuck, the hole could be lost. Other shale types can be very stable in the presence of water and are not difficult to drill through with water-based drilling fluids (called drilling muds). In practice, a shale formation may consist of a mixture of different clay mineral types, so the reactivity of shale to water can vary from mild to severe. Chemicals are usually added to the drilling fluid to decrease (inhibit) the hydration reaction of such shales (**Fig. 2-6**).

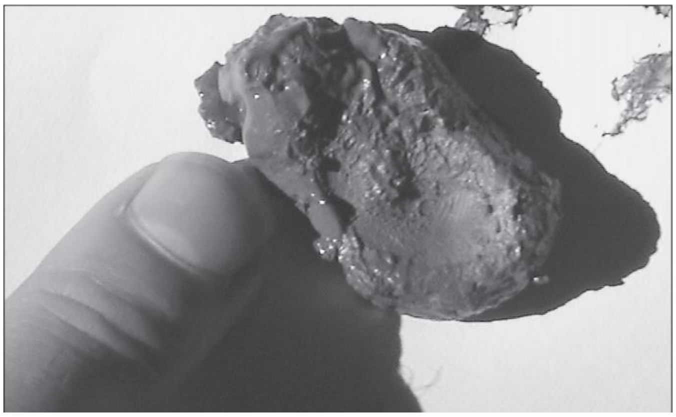

Figure 2-6 Soft, hydrated shale from a well

Clays are deposited in very low energy environments as they are built from small to very fi ne particles. In order for these to be deposited, the water must be almost still. Such environments would be found in very deep water or in swamps and lakes.

Some shale minerals are completely unreactive to water (such as mica), while others may react with water to a lesser or greater extent. Some shales will consist of a mix of shale minerals.

Shales form about 75% of all sedimentary rocks and cause about 90% of all geology-related drilling problems. Successful drilling engineers need a good understanding of shale chemistry and physical attributes in order to drill wells to economically reach their objectives.

2.2.4.1. Sandstones

A sandstone structure consists of particles of sand (mostly quartz grains, often colored by the presence of traces of other minerals, such as iron). The sand grains are pressed together by the weight of the sediments deposited above (***Fig. 2-7***). In the spaces between the grains was originally water, which may contain all sorts of dissolved minerals and salts. Over time, materials may come out of solution and be deposited where the grains come into contact with each other. This cementation might be strong or weak, depending on the minerals involved and on how much is deposited. With weak cementation, the sandstone may start to fall to pieces when drilled through. If it is a reservoir rock, the flow of hydrocarbons from the formation into the producing well may bring sand with it, which can damage or block production equipment if the well is not designed to prevent it.

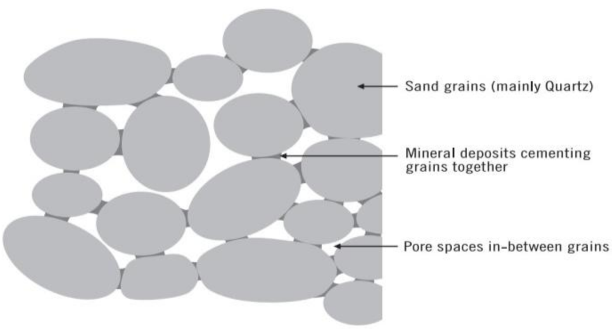

Figure 2-7 Sandstone structure

Within a sandstone structure, clay minerals might also be found. Clays cause serious problems in a reservoir if they react with water (perhaps from the drilling fluid) because they can block the flow of hydrocarbons to the well.

Strongly cemented sandstones can be quite abrasive, leading to high rates of wear on the drill bit and other downhole components. Sandstones make up about 11% of all sedimentary rocks. For a sandstone (or other rock) to be capable of acting as a reservoir, there are two vital physical properties that it must have: porosity and permeability.

Porosity is a measure of the percentage of the volume of the rock that is occupied by fluids. In **Fig. 2-7**, the white spaces are marked as “Pore spaces in between grains.” This sandstone therefore has porosity.

Permeability is a measure of the ability of fluids to flow through the rock. For this to happen, the pore spaces must be connected in such a way that fluids can flow along the pore spaces. It is possible for a rock to have porosity but be impermeable (shales are an example). It is not possible for a rock to be permeable but have no porosity.

2.2.4.2. Carbonates

Carbonates are composed of fossilized skeletons and mineral grains of calcite (crystals of calcium carbonate; chemical formula CaCO3). Crystalline limestone is very common, and its texture can be seen by rotating the rock and observing the light reflected off the numerous crystal faces. The crystals are soft enough to be scratched by a knife.

Fossiliferous limestone is similar to crystalline limestone except that it contains fossil fragments, usually composed of calcium carbonate. Most limestones are fossiliferous.

Carbonates are often fractured due to their brittle nature. Fractured carbonates make prolific reservoir rocks, as the oil and gas can collect in the fractures. Since the permeability of fractures is very high, if a well intersects many fractures, it can produce oil at very high rates. However, drilling through fractured carbonates can cause large volumes of drilling fluid to be lost into the formation. Sometimes these formations have to be drilled with special techniques, such as using foam as a circulating medium rather than liquid mud.

Limestones often contain chunks of chert (flint), which is an amorphous (without crystals) form of quartz. It results from the percolation of silica rich pore fluids. The rock breaks along curved surfaces, forming knife edges and sharp points. Cherts can break teeth on drill bits while drilling. Carbonates comprise about 13% of sedimentary rocks.

2.2.4.3. Evaporites (salts)

Evaporite sequences occur as a result of sea water evaporating, leaving the soluble salts behind. There is a definite order of precipitation, as the least soluble salts come out of solution and are deposited first. The most soluble salts, which come out of solution last, are various rare potassium and magnesium salts. These latter salts are very soluble and would only precipitate out if dehydration was almost complete.

The complex sequences present in a mixed salt formation lead to several problems that cannot be solved by using a conventional (NaCl) salt-saturated, water-based drilling mud as a circulating fluid. The highly soluble magnesium and potassium salts will dissolve in a sodium chloride saturated solution. This can give greatly enlarged holes with many attendant problems.

Some types of salt can flow just as ice in a glacier flow. It can create tremendous forces that act on any obstacle in its path, such as a well. It is possible for flowing salt to break a well in half or to crush the steel casing that lines the well. Salt can flow so fast that a hole can close around the drill bit as it drills, stopping the bit from turning. Often when that happens, fresh water has to be pumped down around the bit to dissolve some of the salt in order to free the bit.

As salt is lighter than most other rocks, bubbles of the salt can try to rise up through the rock above it, like a bubble of oil rising through water. Of course, it takes millions of years for this to happen, rather than a few seconds. These salt domes can be huge and can create traps for hydrocarbons.

2.2.5. Sharyoof field Lithostratigraphy / Sayun-Masilah Basin

Geological interpretation had been done for Sharyoof field according to drilling and mud reports as following:[1]

2.2.5.1. Umm Er Radhuma Formation:

Start from the surface to ± 224 m (thickness: 218 m). From electric logs and correlation with one of well a thin (2m) Claystone horizon is present at the base. This was not observed in the cuttings samples. Limestone, Mudstone: white, off white, cream, occasionally red to pink stain, moderately hard to hard, blocky in part, Conchoidal fracture, commonly rock flour, Micrite, trace loose fine grained calcite, locally dolomitic. Mudstone grading to Wackestone, occasionally dolomitic, trace to common forams, no visible porosity, no shows.

Dolomitic Grain stones: off white, medium grey to medium greyish brown, occasional black specks, generally hard to very hard, firm to moderately hard in part, occasionally friable, Sucrosic, fine to medium grained, no visible porosity, no shows. Below 180m there was an increase up to 40% of Dolomitic Grainstone: medium brown to dark brown, dark orange brown, occasionally transparent, friable to very hard, flaggy, fine to coarse dolomite grains, Sucrosic in part, common black to dark brown specks, predominantly no visible porosity, trace moderate inter-granular porosity, no shows, becoming commonly buff, microcrystalline, occasionally fine coarse grained below 200 m.

2.2.5.2. Sharwayn Formation:

Massive Shale interval: ±224 m to ±250 m (thickness: 26 m). This Formation was seen as a Claystone sequence with thin Dolomites. Locally the Formation was silty to very silty and sandy. Claystone: dark grey, dark grey to very dark grey, medium grey, soft to firm, generally plastic, occasionally sub-blocky to blocky, rarely platy, predominantly non calcareous and non-dolomitic, locally silty to very silty, in part grading to Siltstone, occasionally very fine to fine grained quartz (sub-angular to sub rounded) grains, rare to occasional fine pyrite nodules and very finely disseminated pyrite. Also Claystone: trace light orange brown, soft to fine, platy, moderately calcareous and dolomitic. Dolomite: Grainstone, orange brown, trace red stain, occasionally clear, soft to fine. friable, commonly Sucrosic, fine to medium grained, predominantly angular, locally silty to very silty, occasionally argillaceous inclusions, occasionally very fine quartz, grading to Dolomitic Siltstone, predominantly no visible porosity, rare inter-granular porosity, no shows.

2.2.5.3. Mukalla Formation:

Can be divided in 3 sections: The upper section: is mainly composed of sand with rare intercalations of clay, clay stone and sandstone. The middle section consists of alternating sand, clay and clay stone with rare levels of organic shale.

The lower section: is more Pelitic and consists of an alternating of clay stone and siltstone and sandstone. The Mukalla Formation was predominantly unconsolidated Sands interbedded with Claystone from ±250 m to ±460 m:

Predominantly Sandstone interbedded with Claystone. Sandstone: White to off white, occasionally medium grey to light brownish grey, clear, transparent to translucent, pink to orange stain, generally fine to very coarse grain, occasionally very fine to fine, poor sorting, poor to moderate sorting in part, angular to sub-rounded, occasionally very well rounded, spherical to sub-spherical, predominantly loose Quartz, occasional poor to moderately hard siliceous cement, locally argillaceous, locally common nodular Pyrite, locally fine black carbonaceous material, non-calcareous and non-dolomitic, no visible porosity, good inferred intergranular porosity, no shows.

Claystone: Light grey to medium grey, olive grey to light brownish grey, dark grey to greyish black in part, predominantly soft, occasionally firm, commonly hydroscopic and swelling, plastic, occasionally blocky to sub-blocky, predominantly massive, amorphous, occasional to common very fine black carbonaceous material, occasionally very carbonaceous, non-calcareous, locally silty, occasionally associated with very fine to fine grained Quartz. From 460 m to ±610 m:

Claystone interbedded with frequent Sandstone. Sandstone: White to off white, occasionally medium grey, transparent to translucent, trace to common faint pink staining, fine to very coarse grain, poor to moderate sorting, sub-angular to sub-rounded, sub-spherical, predominantly loose Quartz, trace to occasional poor to moderately hard siliceous cement, rare slightly dolomitic cement, trace argillaceous, occasional nodular Pyrite, trace very fine to coarse black carbonaceous material, non-calcareous, no visible porosity, good inferred intergranular porosity, no shows.

Claystone: Medium grey, light to dark grey, olive grey to brownish grey, occasionally off white to white, very soft to firm, occasionally firm, generally plastic, hydro-Scopic, swelling, dispersive, occasionally sub-blocky to blocky, occasional to common finely disseminated carbonaceous material, very slightly silty in part, rare to trace hard fine to coarse calcareous and dolomitic inclusions. Also as a very carbonaceous Claystone: very dark grey to black, very soft to fine. Sticky, plastic, hydroscopic, swelling, waxy Lustre, organic, very carbonaceous, (bituminous), non-calcareous and non-dolomitic. Rare traces of Dolomite / Dolomitic Limestone: (Mudstone), hard, blocky, microcrystalline from 610 m to 649 m:

Sandstone interbedded with Claystone. Claystone becomes silty towards the base of the section. Sandstone: White to off white, occasionally medium grey to light grey, transparent to translucent, trace to occasional pink staining, predominantly very fine to fine grain, occasionally medium to very coarse grain, poor to moderate sorting, sub-angular to sub-rounded, occasionally very well rounded, sub-spherical, predominantly loose Quartz, occasional poor to moderately hard siliceous cement, rare slightly dolomitic cement, trace argillaceous, occasional nodular Pyrite, trace light green Glauconite, trace very fine to coarse black carbonaceous material, no visible porosity, good inferred intergranular porosity, no shows.

Claystone: Light to dark grey, dark yellowish brown, brownish grey, bluish grey, occasionally off white to white, very soft to firm, occasionally firm, generally plastic, hydroscopic, swelling, occasionally sub-blocky to blocky, occasional to common finely disseminated carbonaceous material, occasionally silty to very silty.

2.2.5.4. Fartaq Formation:

Massive limestone layers interbedded with claystone The Fartaq Formation consists of an upper Dolomite followed by interbedded Claystone and Limestone. Dolomite: Pale yellowish brown, hard to very hard, microcrystalline, elongated in part, well indurated, Conchoidal to angular fracture, no visible porosity, no shows.

Claystone: Medium grey to olive grey, dark yellowish brown, firm to moderately hard, sub blocky to sub-platy, very soft to fine, plastic in part, swelling, dispersive, non-calcareous. Limestone: Mudstone, white, off white, generally very soft, occasionally firm, amorphous, very dispersive, occasionally sub blocky, microcrystalline to cryptocrystalline, no visible porosity, no shows.

2.2.5.5. Harshiyat Clastic Formation

Harshiyat Formation consists of an upper section of predominantly Claystone, minor Sandstone and Siltstone. A middle section predominantly Sandstone and Claystone. A lower section of interbedded Sandstone and Claystone.

Upper Section

Claystone, minor Sandstone and Siltstone. Rare stringers of Dolomite.

> ***Claystone***: Dark grey to olive black, bluish grey, light to dark yellowish brown, occasionally pinkish grey, generally very soft to firm, generally plastic, sub-blocky to sub-platy in part, hydroscopic and swelling, dispersive, occasional very fine brown to black specks, very rare light green flaky mineral (Chlorite), rare very fine Quartz grains, non-calcareous, locally grading to Argillaceous Siltstone.
>
> ***Sandstone***: White to off white, light grey, transparent to translucent, predominantly very fine to fine grain, trace fine to medium grain, moderately sorted, sub-angular to angular, occasionally very well rounded, predominantly loose Quartz, trace to occasional hard siliceous cement, occasional nodular Pyrite, no visible porosity, locally moderate to good inferred porosity, no shows.

Siltstone: Medium brown. very soft to firm, plastic, sub-blocky in part, hydrocopic and swelling, dispersive, argillaceous to very argillaceous, occasional very fine Quartz grains, common fine black carbonaceous specks, non-calcareous and no dolomitic.

Dolomite: (rare to trace): Off white to pinkish grey, brownish grey, very hard. blocky in part, angular to Conchoidal fracture, argillaceous in part, occasional very fine to fine sand. in part grading to very fine Dolomitic Sandstone, no visible porosity, poor inferred porosity, no shows.

Middle Section

Sandstone interbedded with Claystone, Carbonaceous Claystone and Siltstone. Rare Dolomite stringers and rare Sandstone Clasts.

Sandstone: White-off white, light grey to light brownish grey, dark yellowish brown, transparent to translucent, predominantly fine grain to coarse grain, locally very coarse, occasionally fine to very fine, moderately sorted, sub-angular to angular, sub-rounded to rounded in part, occasionally very well rounded, predominantly loose Quartz, locally abundant off white rock flour, trace to occasional moderately hard to hard siliceous cement, rare to trace siliceous and slightly dolomitic cement, trace to common nodular Pyrite, occasionally abundant nodular Pyrite, no visible porosity, moderate to good inferred porosity.

Sandstone Clasts: Dark brown, fine to medium, very hard, poor sorting, angular to rounded, very hard siliceous and argillaceous cement fine to coarse hard argillaceous and silt clasts, non-calcareous and non-dolomitic, no visible porosity, poor inferred porosity, no shows.

Siltstone: Medium brown, soft to firm, plastic, sub-blocky in part, very fine black carbonaceous specks, trace very fine Quartz argillaceous to very argillaceous, non-calcareous and non-dolomitic no shows.

Claystone: Orange grey to dark yellowish brown, pale yellowish brown to brownish grey, medium grey, bluish grey, red to pinkish grey, dark grey to very dark brownish grey, generally very soft to fine, occasionally moderately hard, generally plastic, sub-blocky to blocky in part, predominantly hydroscopic and swelling, dispersive, trace to occasional earthy and waxy Lustre, occasional very fine black carbonaceous specks, locally very carbonaceous, locally occasionally silty to very silty, occasional traces very fine Quartz, non-calcareous.

Carbonaceous Claystone: Black, very dark grey, brownish black, firm to soft, occasionally moderately hard, sub-blocky to blocky, brittle in part, occasionally sub-vitreous Lustre, abundant very fine to submicroscopic black carbonaceous material, abundant very fine Pyrite, occasional very fine to submicroscopic Pyrite laminations, non-calcareous and non-dolomitic, locally grading to Coal/Lignite, no shows.

Dolomite: (rare stringers): Off white to pinkish grey, pale yellowish brown to greyish orange, very hard, blocky in part, angular to Conchoidal fracture, rarely argillaceous, rare very fine sand, locally common very fine sand, in part grading to Dolomitic Sandstone, no visible porosity, no to poor inferred porosity, no shows.

Lower Section

Claystone interbedded with Sandstone. Minor Limestone stringers. Trace Siltstone towards the base.

Claystone: Bluish grey to dark greenish grey, medium grey, light grey, pale yellowish brown, trace dark grey, generally soft to firm, occasionally moderately hard, commonly plastic, sub-blocky to platy, occasionally sub-fissile to fissile in part, occasionally splintery and elongate, occasionally hydroscopic and swelling, silty in part, trace nodular Pyrite, trace carbonaceous locally grading to Carbonaceous Claystone.

Carbonaceous Claystone: Black, very dark grey, brownish black, firm to soft, occasionally moderately hard, sub-blocky to blocky, brittle in part, occasionally sub-vitreous Lustre, abundant very fine to sub-microscopic black carbonaceous material, abundant very fine Pyrite, occasional very fine to microscopic Pyrite laminations, non-calcareous and non-dolomitic, no shows.

Sandstone: White-off white, light grey to light brownish grey, transparent to translucent, predominantly fine grain, occasionally medium grain, rarely coarse grain, moderately sorted, sub-angular to sub-rounded, very well rounded in part, occasionally very well rounded, moderately spherical, predominantly loose Quartz, locally abundant white rock flour, trace to occasional hard siliceous cement, rare to trace siliceous and slightly dolomitic cement, trace to common nodular Pyrite, occasionally abundant nodular Pyrite, common to abundant carbonaceous material, no visible porosity, moderate to good inferred porosity. Increasingly well cemented and calcareous/dolomitic towards the base Shows: trace to very poor shows from fine, friable Sandstone: trace black to brown stain/deposit (very carbonaceous. tarry). no odor no direct Fluorescence, very slow streaming yellow to white crush cut fluorescence, nil to very faint tea color cut black residue, moderately bright yellow to white residual ring fluorescence

Siltstone: Medium brown, soft to firm, plastic, sub-blocky in part, very fine black carbonaceous specks, trace very fine Quartz, argillaceous to very argillaceous, non-calcareous and non-dolomitic, no shows.

2.2.5.6. SEAL Formation:

Shale interval intercalated in the lower part with limestone and argillaceous limestone.

2.2.5.7. QISHN Formation

Calcareous interval from hard crystalline limestone to calcareous clay stone.

2.2.5.8. RED SHALE Formation

Massive shale layer with very rare intercalations of limestone.

2.2.5.9. Biyadh Formation

Upper Biyadh Limestone Formation

- Massive limestone interval with intervals of shale grading to clay stone.

Upper Biyadh Sandstone Formation

- Alternating sandstone and shale.

Middle Biyadh Formation

- Mainly sandstone interbedded with dark reddish clay stone.

Lower Biyadh Formation

- Clastic interval with intercalations of sandstone and siltstone.

2.2.5.10. Sarr (S1) Formation

Calcareous-dolomitic interval. Saar Carbonate was predominantly Dolomite, with minor Limestone.

Dolomite: Very pale orange, greyish orange to pale yellowish brown, hard to very hard, Conchoidal fracture, well indurated, generally crystalline, in part microcrystalline to cryptocrystalline, no visible porosity, poor inferred porosity.

2.2.5.11. Sarr (S4) Formation

Mainly dolomite occasionally grading to dolomitic limestone. Limestone: generally, mudstone, occasionally mudstone to packstone, off white to white, medium to light grey, fine, fine black laminae, very fine pyrite, locally Sucrosic, locally very argillaceous and silty, grading in part to calcareous claystone, dolomitic in part, no visible porosity, poor inferred porosity, no shows.

2.2.5.12. Naifa Formation

Massive limestone layer with organic shale on bottom.

2.2.5.13. Madbi Formation

- Shale.

- Limestone.

2.2.5.14. Shuqra and Kuhlan Formation

Alternating anhydrite, limestone and shale formation.

2.2.5.15. Basement

Fractured granite or similar.

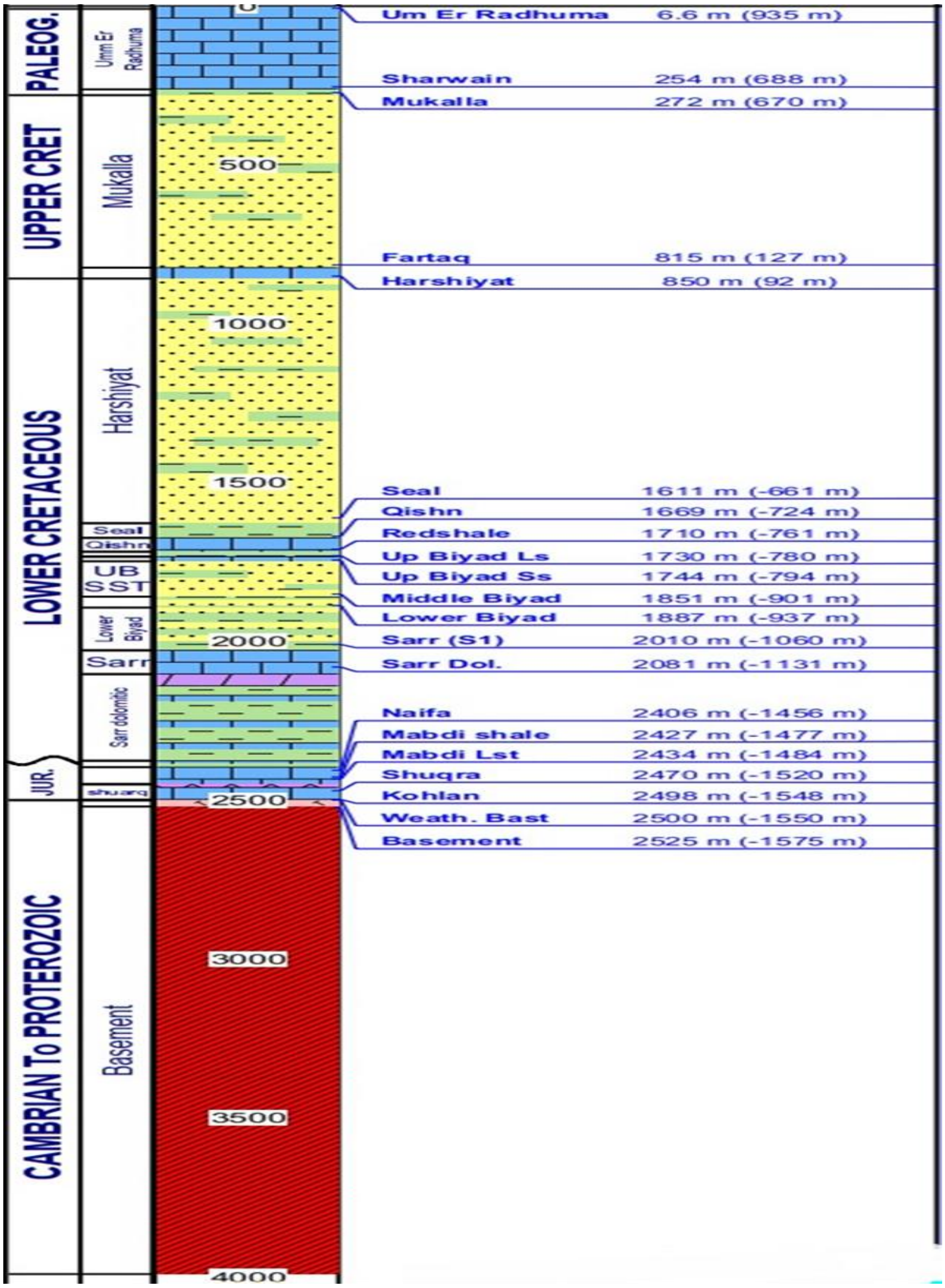

Figure 2-8 Sharyoof field Lithostratigraphy / Sayun-Masilla Basin Column

2.3. Hole Problems

2.3.1. Overview:

Only events which cause the drilling operation to stop are described as Non-Productive Time (NPT) events. Pipe sticking and lost circulation are two of the main events causing NPT in the drilling industry. Well Kicks of course require operations to stop and when they Occur can result in a large NPT. The average NPT in the industry is 20%.[3]

2.3.1.1. Stuck Pipe:

Stuck pipe is one of the more common and serious drilling problems. It can range in severity from minor inconvenience, which can increase costs slightly, to major complications, which can have significantly negative results, such as loss of the drill string or complete loss of the well. A large percentage of stuck pipe instances eventually result in having to sidetrack around the stuck pipe called a fish and re-drill the interval. Depending on Sticking causes we can avoid stuck pipe and correct it efficiently, it is important to understand the various causes and symptoms so that proper preventive measures and treatments can be taken. In general, pipe becomes stuck either:

a) Mechanically sticking is caused by a physical obstruction or restriction.
b) Differential sticking which caused by differential pressure forces from an overbalanced mud column acting on the drill string against a filter cake deposited on a permeable formation.[4]

Table 2-1 Pipe Sticking Mechanisms and Causes

	Differential Sticking	Mechanical Sticking	
Cause	Differential forces	Settled Cuttings	Stiff BHA
	High overbalance pressures	Shale Instability	Key Seating
	Thick filter cakes	Fractured Rocks	Mobile Formations
	High-solids muds	Cement Blocks	Under-gauge Hole
	High-density muds	Junk	Micro Doglegs and Ledges

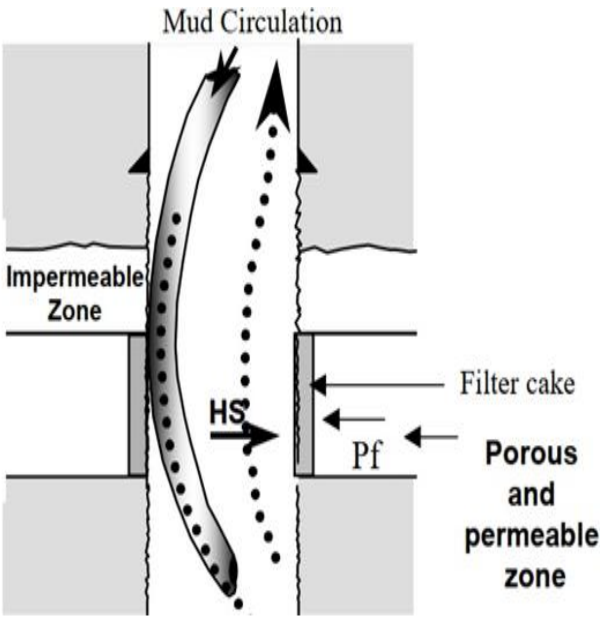

Figure 2-9 Differential Sticking

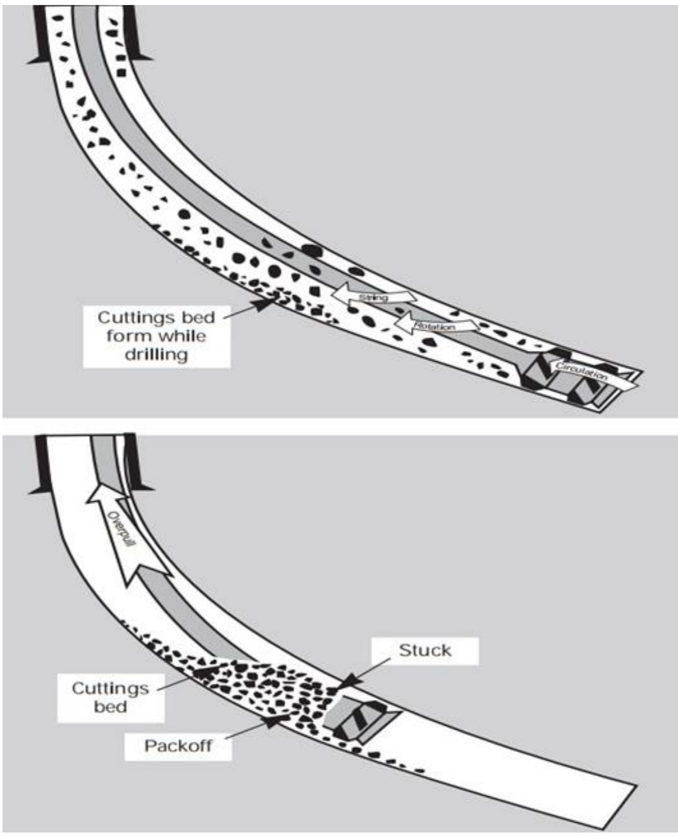

Figure 2-10 Settled cuttings

2.3.1.2. Tight Hole

A hole is said to be tight when the upward force is greater than the buoyant weight of the drill string. The extra force above the buoyant weight is called the drag force. Increased drag while drilling or pulling out of hole is a clear indication that the hole is becoming tight, which observed across sections containing reactive clays. The swelling of the clays results in a reduced wellbore diameter eventually causing increased drag when pulling out of hole.**[5]**

2.3.1.3. Hole Washout and Erosion

A washout is an increased in diameter in a section of the hole being drilled. Hole erosion and washout occurs across weak and soft formations as a result of using excessive mud annular velocities. Washouts also occur across reactive shales which slough into the hole when contacting uninhibited water-based mud.

Signs of washouts at surface include:

- Increased volume of cuttings on shale shaker.
- Large cuttings.
- Difficulty in running into the hole.
- Bottoms up time increase.

Hole washouts cause several problems including difficulty in cleaning the hole, poor directional control, difficulty in running into the hole and most importantly result in very poor cement job.

2.3.1.4. Shale and Wellbore Stability

Maintaining a stable wellbore is one of the major challenges when drilling a well. Preventing shale instability is a high priority to every phase of the drilling fluids industry, from research and development efforts to field implementation by the mud engineer. Wellbore instability is caused by a radical change in both the mechanical stress and the chemical and physical environments when a hole is drilled, exposing the formation to drilling mud. Hole instability is seen most often as sloughing and caving shale, resulting in hole enlargement, bridges and fill. The most common consequences are stuck pipe, sidetracks, logging and interpretation difficulties, sidewall core recovery difficulties, difficulty running casing, poor cement jobs, and lost circulation. All contribute to increased costs, the possibility of losing part of the hole or the entire well, or reduced production. Wellbore instability is caused by:

- *Mechanical stress:*
  - Tension failure: fracturing and lost circulation.
  - Compression failure: spalling and collapse or plastic flow.
  - Abrasion and impact.
- *Chemical interactions with the drilling fluid.*
  - Shale hydration, swelling and dispersion.
  - Dissolution of soluble formations.
- *Physical interactions with the drilling fluid.*
  - Erosion.
  - Wetting along pre-existing fractures (brittle shale).
  - Fluid invasion — pressure transmission.

A number of possible causes must be evaluated in resolving wellbore instability. By evaluating these interrelated conditions, the most likely failure mode can be determined and an appropriate response can be applied to resolve or tolerate the instability.

These include mechanical conditions such as:

- Hole cleaning problems.
- Wellbore erosion.
- Physical impact damage.
- Mud weights and pore pressures.
- Surge and swab pressures.
- Wellbore stresses.

Chemical conditions also must be evaluated such as:

- Reactivity of the failing formation.
- Chemical compatibility of the mud system.
- Possible wellbore dissolution.

2.3.1.5. Lost Circulation

Losses of whole mud to subsurface formations is called lost circulation or lost returns. [6]Lost circulation has historically been one of the primary contributors to high mud costs. Other hole problems such as wellbore instability, stuck pipe and even blowouts have been the result of lost circulation. Besides the obvious benefits of maintaining circulation, preventing or curing mud losses is important to other drilling objectives such as obtaining good quality formation evaluation and achieving an effective primary cement bond on casing. Lost circulation occurs in one of two basic ways:

- **Invasion** or mud loss to formations that are cavernous, Vugular, fractured or unconsolidated.
- **Fracturing** which is mud loss due to hydraulic fracturing from excessive induced pressures.

Figure 2-11 Lost-circulation sections:

a. High-permeability unconsolidated sands and gravel.
b. Cavernous or Vugular zones in carbonates (limestone or dolomite).
c. Natural fractures, faults and transition zones in carbonates or hard shales.
d. Induced fractures from excessive pressure.

2.3.2. Wells Drilling:

During drilling stage of oil and gas industry drilling crew have met some of wells instability at this basin, as shown by Well Progression Chart at Say'un-Masila basin that the well divided into 4 sections which is detailed at table below:

Wells which we will studying are divided with same design and TD is same like this one. where all of wells are going into Basement reservoir as a target depth. All of sections will explain with drilling process that applied into every section as alone as follow:

Table 2-2 Well Sections drilling process

Phase	Casing setting point	MD/RT
17 ½ " OH 13-3/8" csg	Top of Harshiyat	**849 m**
12 ¼ " OH 9-5/8" csg	Weathered Basement	**2788 m**
8 ½ " OH sc 2-3-4	Basement	**N/A**
6" OH sc 2-3-4	Basement TD	**N/A**

2.3.2.1. Wellbore with ($17^{1/2}$ inches) Phase:

- *Phase Objective and TD (+/- 852m):*

The purpose of this phase is to cover the fractured Dolomite in U. E. RADHUMA and the thief zone of the MUKALLA formation and to protect the two aquifers. Section TD, +/- 10 m into the Harshiyat formation.

- Geology
    - Umm Er Radhuma
    - Sharwayn
    - Mukalla
    - Fartaq 3
    - Top Harshiyat

- *Important points*

$17^{1/2"}$ drilling will be drilled using rotary BHA & foam to +/-297 m. Thereafter, $17^{1/2"}$ drilling will be drilled using rotary BHA and aerated Mud to TD. 13 3/8" shoe to be set +/-7 m into Harshiyat formation. Redundant SPP reading to be available at all time (cf incident on KHA1-26).

- *Bottom Hole Assembly*
  - BHA #1 to spud well and drill to +/- 50m. WOB= 3.5 T.
  - BHA #2 to spud well and drill to 297m. WOB MAX = 6.6 T.
  - BHA #3 drill to TD. WOB MAX = 20 T.

- *Bit program & Parameters*

$17^{1/2"}$ Tricone Bit T1 will be selected according to last call for tender, Bit Make-Up torque: 36,000 ft-lbs. TFA=1.48 in^2, WOB = 5 to 20T, RPM = 80 – 100, Flow rate = 2500 lpm.

Instant ROP to be limited to 30 m/h (+/- 20 m/h including connections).

- *Foam Drilling*

Table 2-3 Foam drilling System

Air Flow	3200 scfm (up to 3600 scfm)
Water Flow	20 - 25 GPM
Foaming agent	0.5 %

- *Aerated mud Drilling*

The aerated mud drilling program has been designed in order to have the minimum pressure in front of the shallow weak zones while keeping an overbalanced condition in the Mukalla Aquifer.

- Mud properties:

Table 2-4 Drilling Mud Properties

Mud Weight:	1.04 -1.09 SG Max
Funnel Viscosity	70 - 80 Sec
Yield Point	20 - 25 lbs/100 sq ft
Filtrate	10 - 15 cc/30mn
PH	>9.0

- *Drilling operations*

Drilling started with 17-3/4" rotary BHA and foam in order to reach the Mukalla then continue drilling with 17-1/2" rotary BHA and aerated mud. Section TD when entering into Harshiyat formation.

- *Casing and cement*

- Keep 3 m rat hole for 13-3/8" casing shoe. Run casing to bottom as per casing program.
  - 1 x 13"3/8 Guide shoe
  - 2 x 13"3/8 casing joints
  - 1 x 13"3/8 non rotating PDC drillable float collar
  - Xx 13"3/8 casing joints
  - CHH and landing joint
- The casing cemented with 2 slurries up to surface:

Table 2-5 Casing Slurry properties

	LEAD	**TAIL**
Slurry height	To surface	200 m
Slurry weight	1.52 SG	1.90 SG
Volume	59 m^3	17 m^3
Class G	43.5 mt	22 mt
Excess	20 %	10 %
Fluid Loss	N/A	< 200 cc
TT	5 hours	4 hours

- The cement job was performed conventionally with top & bottom rubber plugs and dual cementing head.

- *Main Problems*

Well "A"

- Drilling break: at 270m.
- Losses at: 328 m to 358 m after connection.
- Blind Drilling: from 294 m to 381 m
- Differential Sticking: at +381m, lost bottom of BHA in hole could not recover it. Drill String plugged.

Well "D"

- String stuck after circulation break at 440 m/RT - No rotation - Work pipe until free.

2.3.2.2. Wellbore with 12''1/4 PHASE

- *Phase Objective and TD (+/-2792m TMD)*

The objective of this phase is to cover and isolate the hydrocarbon bearing reservoirs of Biyadh and Sarr down to the Basement formation. The hole will be drilled vertical to 2510 m, inclination will then be built to 32.2° in azimuth 222.6° at 4.5°/30m. Then section will be drilled slant to section TD expected at 2912 m into the basement

- *Geology*.
  - HARSHIYAT
  - SEAL
  - RED SHALE
  - BIYAD LIMESTONE
  - UPPER BIYAD SANDSTONE
  - MIDDLE BIYAD
  - LOWER
  - SARR (S1)

- SARR (S4)
- NAIFA.
- MADBI Shale
- MADBI Limestone
- SHUQRA
- KHOLAN
- Weathered BASEMENT
- BASEMENT

- *BHAs & Bits*

12 ¼" PDC2 & 12 ¼" T2 Tricone will be selected according to last call for tender

BHA #0 was with 12 ¼'' Utility bit, TFA= 0.78in^2. Max. WOB 6 Tons.

BHA #1 will be a pendulum BHA with PDC bit (852-2054m). Max. WOB 6 Tons.

BHA #2 will be a pendulum BHA with MWD tool and PDC bit (2054-2792m) with Max. WOB 6 Tons.

- Drilling parameters
  - Flow rate: 2900-3000 l/min.
  - WOB / RPM Pendulum BHA: limit WOB to 6 Tons and keep high RPM from 135 to 140.
  - The seek for optimum ROP must drive us to optimize the above parameters on regular basis but controlled ROP might be required in order to avoid losses while drilling with PDC bits.
- Mud
  - **Type of mud:**

    KCl / Polymer / Asphasol.

- **Volume required:**

Table 2-6 Volume Required

Casing volume	+/-65 m3
Surface volume	+/-180 m3
Open hole	+/-135 m3
Dilution	+/-900 m3
9Sum of Volume Required	+/- 1300 m3

- Drilling operations
    - The hole will be drilled vertical to 2510 m with a pendulum BHA (BHA1).
    - Inclination will then be built to 32.2° in azimuth 222.6° at 4.5°/30m to 2724 m (BHA2).
    - Dog leg not to exceed 6°/30m.
    - Ream each stand twice before connection if necessary.
    - Prior to any trip out, the hole could be circulated clean with Sun sweep pill depending on hole condition.
    - Section will be drilled +/-40m into the Basement.

- *Main Problems*

- ***Well "A"***
    - Tight hole at 2442m, 1900m and 1850
    - Hole packed off on connection from 2410m to 2500m
- ***Well "B"***
    - **Total losses** at various depth 1526m, 1538m, 1039m
    - **Tight spot** (Hole) which happened in different stages at 1671m, 1629m, 1614m, 1606m, 1585m, 1578m, 1572m, 1579m, 1531m, 1496m, 1526m, 1444m, 926m, 1022m and 1000m. 1317m, 1269m, 1265m, 1467m to 1192m and from 1063m to 980m, 926m, 1444m and 1537m.
    - **String stuck** at 1422m, 1052, 1040 and 1525m:
        - 1St 1422m success freeing to 1415m and at 1375m. POOH stop at 1375m.

- 2nd 1052m, 1047m, 1040m. POOH stop at 1040m.
- 3rd 1525m and get free.

Well "C"

- **Total losses:** at 1475 m to 1445 m, 1385 m, 1184 m,
- **Tight Spot:** at different depths 901 m, 920 m, 938 m, 949 m, 956 m. From 2895 m to 2879 m, at 2623 m, 1913 m, 1884 m, 1585 m, 1452 m, 2900 m, 2584 m, 2441 m and 2342 m.
- **Pipe Sticking:** 931 m, 2883 m. But drill pipes got free with success.

- ***Well "D"***
  - At 1202 m/RT, break circulation - 26 m3 losses before getting returns.
  - At 1099 m/RT, attempt to break circulation:
    - **total losses.**
    - **Set 5 cement plugs and LCM to cure losses.**

2.3.2.3. Wellbore with 8$^{1/2}$" Phase:

- *Phase Objective and TD (+/- 4015m TMD)*

The objective of this 8"1/2 phase is to drill horizontal drain in the Basement. Build-up to 78° will be initiated from the beginning of the 8"1/2 phase and should be reached at 3065m/RT. The sub-horizontal drain will then be drilled slant to TD.

- *Geology*

  BASEMENT Fractured granite or similar.
- *BHA*

Table 2-7 Clean-out BHA

Qty	Component Description
1	8" ½ Utility bit -TFA=0.64
1	Bit Sub
1	NMDC
1	Drilling Jars
21	HWDP
Xxx	5" Drill pipe 19.5# S135 4-1/2 IF to surface.

Table 2-8 Build up BHA from 2912 to 3012m:

Qty	Component Description
1	8"$^{1}/_{2}$ T1 Tricone Bit - TFA=0.64 in^2
1	DHM Power pack 675 XP 7:8 – 1.83° Bent. 8" $^{3}/_{8}$ Sleeve stab + **flex joint.**
1	MWD + NMDC's
1	Drilling Jars
21	HWDP
Xxx	5" Drill pipe 19.5# S135 4-1/2 IF to surface.

Table 2-9 Build up BHA from 3012 to 3065m:

Qty	Component Description
1	8"$^{1}/_{2}$ T1 Tricone Bit - TFA=0.64 in^2
1	DHM Power pack 675 XP 7:8 – 1.83° Bent. 8" $^{3}/_{8}$ Sleeve stab+ **flex joint.**
1	MWD + NMDC's
1	Drilling Jars
+/-30m	5" Drill pipe 19.5# S135 4-1/2 IF to surface.
21	HWDP
Xxx	5" Drill pipe 19.5# S135 4-1/2 IF to surface.

- *Bit program and parameters*
  - 8"$^{1}/_{2}$ T1 Tricone & Utility Bit will be selected according to last call for tender.
  - RPM: 40, Flow: 1750 LPM.

Table 2-10 Bit program and parameters

BHA	Depth	Max WOB * Rotating (kips)	Max WOB ** Sliding (kips)
Clean-out BHA	---	18	---
Build-up BHA	2928 – 2978	37	51
	2978 – 3028	37	47
	3028 – 3065	36	46

- *Mud*

Water viscosified with XC Polymer (or Aphron 15 % if losses encountered):

The mud used to drill this 8½" section will be newly build polymer mud using drill-water slightly to SG 1.01 viscosified with XC Polymer which offer progressive gels with good YP values for hole cleaning efficiency. The mud will be pre-treated with Sodium Bicarbonate and Citric acid to avoid any cement-contamination during the drill out cement. Drilling the major part of cement with water returning straight to slug pit. The new mud (concentrated solution, pre-treated with bicarbonate) is incorporated in the system to obtain a mud ready to drill formation (run centrifuge and Desilter to discard the cement particles remaining in the water despite the really fine shaker screens (325 meshes).

- Mud composition:

Table 2-11 Mud composition

Drill Water	1 m3
Soda Ash:	1 kg
XC-Polymer:	3 - 5 kg

- *Main problems*

  No problems.

2.3.2.4. Wellbore with 6" Phase

- UBD DRILLING TO 4015 M/RT.

- *Phase Objective and TD (+/- 4015m TMD)*

  The objective of this 8"1/2 phase is to drill sub-horizontal drain at 78° in the Basement. This section will then be drilled slant to TD. The section will be drilled in a conventional over balanced method.

- *Geology*

BASEMENT Fractured granite or similar

- *BHA*

Table 2-12 Clean-out BHA:

Qty	Component Description
1	6" ½ Utility bit -TFA=0.64
1	Bit Sub
21	Joints of 4"3/4 DC - 3½ IF
1	120m of 3½ Drill pipe 15.5# S135 - 3½ IF
1	X-Over 3½ IF pin x 4½ IF box
Xxx	5" Drill pipe 19.5# S135 4-1/2 IF to surface.

Qty	Component Description
1	6" T1 Tricone Bit - TFA=0.64 in^2
1	DHM Power pack 475 XP 7:8 – 1.15° Bent. 5" $^7/_8$ Sleeve stab No flex joint
1	5-7/8" String Stabilizer
1	MWD + NMDC
1	Drilling Jars
Xxx(*)	3½ Drill pipe 15.5# S135 - 3½ IF
21	Joints of 4"3/4 DC - 3½ IF
+/-60 m	104m of 3½ Drill pipe 15.5# S135 - 3½ IF
Xxx	5" Drill pipe 19.5# S135 4-1/2 IF to surface.

- *Bit program and parameters*
    - 6" T1 Tricone and Utility Bit will be selected according to last call for tender.
- *Mud*

Water viscosified with XC Polymer (or Aphron 15 % if losses encountered)

The mud used to drill this 8½" section will be newly build polymer mud using drill-water slightly to SG 1.01 viscosified with XC Polymer which offer progressive gels with good YP values for hole cleaning efficiency.

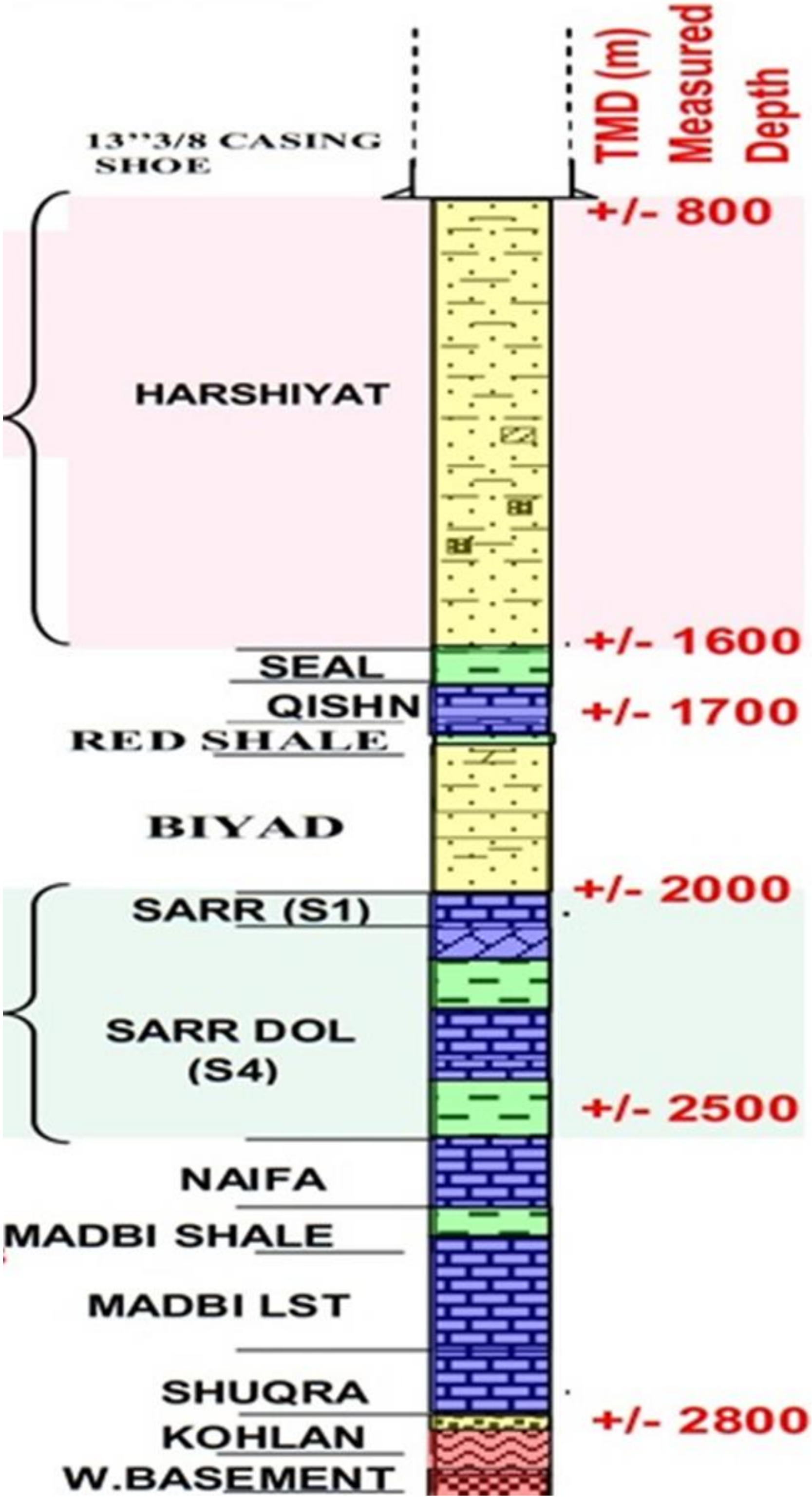

Figure 2-12 Casing Design

2.4. Case Study: Analysis of Wellbore Instability in Vertical, Directional, And Horizontal Wells Using Field Data

An old offshore field produced using vertical and directional wells is being redeveloped by drilling horizontal wells. The experience gained while drilling vertical and directional wells is not useful for drilling horizontal wells, as the failure rate is 1 in 3 holes. Quantification of drilling problems in sixty wells show that majority are tight holes. Stuck pipes and hole pack offs are also significant in number. The major loss of productivity is due to stuck pipes. A preliminary study of shale in sections where problems occur, show no chemical reactivity. Petrographic analysis confirmed the fissile and brittle nature of shale with presence of open, partially healed micro-fractures and partings. Rock mechanical simulation predicted the safe mud weight window for horizontal wells as 76–90 PCF, depending on azimuth. However, all the horizontal wells analyzed in this study were drilled using the same mud weight window. Therefore, field based parameters like initial mud weight used for drilling, mud weight increment and problems per well were used to analyze wellbore instability, identify different instability mechanisms and design safe mud weight window for drilling horizontal wells. These parameters were used first on the drilling data of vertical wells to develop the procedure for the analysis of wellbore instability and identify the mechanisms of instability. The developed procedure was then applied to the drilling data of directional wells to show the dependence of mud weight on the inclination and azimuth of the well. Finally, the procedure was applied to horizontal wells data along with the concept of critical washouts to infer the safe mud weight window as 77–80 PCF in East–West and 82–85 PCF in North–South directions. The safe mud weight window is validated on another set of drilling data showing 90% success rate. The analysis confirms the existence of anisotropy in horizontal stresses and is extremely useful in cases where there is significant variation in mechanical properties of different layers of reservoir rock.[7]

2.4.1. Conclusions

The following conclusions can be made from this study:

- A new method of analyzing wellbore instability using field-based drilling parameters like initial mud weight, mud weight increment, and problems per well is developed.
- The analysis is used to identify three instability mechanisms wellbore wall collapse, differential sticking, and mud invasion/pore pressure penetration.
- The analysis also confirms the anisotropy of in-situ horizontal stresses in the field. The approach is useful when there is lack of information about the magnitude and direction of horizontal stresses.
- This analysis is extremely useful where there is significant variation in mechanical properties of different layers of formation.
- Safe mud weight window for drilling vertical, directional, and horizontal wells is inferred. The window is validated using another set of data from the same field showing 90% success rate.

2.5. Case Study: Wellbore Instability of Shale Formation; Zuluf Field, Saudi Arabia.

Significant wellbore instability problems are being experienced during the drilling of horizontal wells in a Shaly sand member of the Khafji reservoir in Zuluf field. This paper presents the results from a case study that integrates detailed rock mechanics and swelling tests with information from petrophysical logs and core properties acquired to evaluate, define and predict the instability mechanism in this portion of the Khafji reservoir.

The study has tackled the effect of drilling fluid on shale strength and swelling. Additionally, the effects of water activity, osmosis and hydraulic diffusion on shale stability were investigated. The mechanical properties and stress field in the khafji shale was determined. The results provided recommendations to minimize instability problems encountered during drilling. All drilling fluids that have water phase including the oil-based drilling fluid were found to cause instability problems. However all-oil drilling fluid was found to maintain shale strength. Drilling mud salinity to encourage resverse osmosis was determined based on measurement of shale-pore-water salinity. The critical mud weight window was calculated considering the Chemoporoelastic properties of the Khafji shale.[8]

2.5.1. Conclusions

1. The preserved shale core was essential to obtain applicable data and meaningful recommendations to reduce wellbore instability problems of Khafji shale.
2. Based on the shale mineralogy, the Khafji shale has high content of non-swelling clays. Additionally, the Cation Excgange capacity (CEC) is low. Therefore, the instability is caused by dispersion more than swelling.
3. Rock mechanics testing was performed to evaluate the effect of drilling fluids on shale strength. Water based, invert emulsion (oil based), and all oil drilling fluids were tested. All-oil drilling fluid showed the least effect on shale strength.
4. The all-oil drilling fluid showed zero volumetric change during a swelling test.
5. The shale pore water salinity and shale membrane efficiency was determined thus the type of mud, brine, and salinity of drilling fluid is recommended.
6. All data related to mechanical and chemical parameters were determined and the porochemoelastic module of PBORE-3D was used to determine the mud weight window.

2.6. Case Study: Wellbore Stability in Oil and Gas Drilling with Chemical-Mechanical Coupling

Wellbore instability in oil and gas drilling is resulted from both mechanical and chemical factors. Hydration is produced in shale formation owing to the influence of the chemical property of drilling fluid. A new experimental method to measure diffusion coefficient of shale hydration is given, and the calculation method of experimental results is introduced. The diffusion coefficient of shale hydration is measured with the downhole temperature and pressure condition, then the penetration migrate law of drilling fluid filtrate around the wellbore is calculated. Furthermore, the changing rules of shale mechanical properties affected by hydration and water absorption are studied through experiments. The relationships between shale mechanical parameters and the water content are established. The wellbore stability model chemical-mechanical coupling is obtained based on the experimental results.

Under the action of drilling fluid, hydration makes the shale formation softened and produced the swelling strain after drilling. This will lead to the collapse pressure increases after drilling. The study results provide a reference for studying hydration collapse period of shale.[9]

2.6.1. Conclusion

Water content at different distance from the end face of shale sample is measured using the designed equipment in the condition of downhole temperature and pressure.

The water content of shale at the wellbore wall reaches to saturated state quickly when the wellbore is opened; the water content of shale would decrease with the increment of distance from wellbore axis, and the decreasing rate is the highest near the wellbore wall.

Due to the impact of shale hydration, the strength of the circumferential formation around the well is gradually reduced with the increase of drilling time and increases with the increase of the distance away from the wellbore.

Collapse pressure of shale increases sharply in a short time after drilling and then slows down. The collapse pressure is basically steady after several days of the open-hole time. The initial stable wellbore may collapse with the increase of the open-hole time.

Shale containing more smectite is more prone to react with drilling fluid. The possibility of wellbore instability of shale is higher with more smectite as the increasing range of collapse pressure is larger.

CHAPTER THREE

3. METHODOLOGY

3.1. Overview

This project is focusing on studying the wellbore instability problem causes that happened on Sharyoof field in Block 53/Say'un-Masilah Basin and find out the favorable solution for this problem by analyzing the geological and drilling reports which give clear view about the problem in addition to mud logging report. This analysis had done for 4 wells. By using the available data, depth of interest and well parameters have been considered as shown in **Table. 3-1**.

Table 3-1 Formation of Interest

Formation	mv/RT	m/MSL	Thickness
Fartaq	860.45	147.0	35.50
Harshiyat	895.94	111.5	779.97
Seal	1675.91	-668.4	54.50
Sarr	2074.89	-1067.4	60.98
Sarr (D)	2135.88	-1128.4	387.37

3.2. Type of Data That Needed for The Project

Table. 3-2 shows the data that will be used in our study:

Table 3-2 Data needed for the project

No	Data types
1	Real time Log with Name
2	Wells Schematics
3	Daily Drilling Report
4	Mud properties Report

3.3. Analysis Approach:

Analysis approach for the available data is Qualitative, Quantitative Descriptive, and Analytical approach. Comparing the different drilling daily reports for 4 wells will be analyzed and the results will be summarized to show the essential reasons of instability which occurs at the interval of interest. According to the results, recommendation will be presented to avoid this problem permanently or give solution that can reduce the effects of this problem.

3.4. Expected Results:

After Analysis processes be done depending on data which previously mentioned, the following expected results is considered:

1. Drilling at phase $12^{1/4"}$ should be reduce as re-designing process for casing.
2. Find out tripping instruction during drilling 17 ½” & 12 ¼” phase sections.
3. Drilling fluids would be changed to increase its efficiency.

As the final stage of the correlation process the recommended solutions which may give better result to cure the lost circulation which lead to the interest problem “String Stuck”.

CHAPTER FOUR

4. WELLBORE INSTABILITY PROBLEM ANALYSIS AND DISCUSSION

4.1. Introduction

The available data had been analyzed for four wells "A, B, C, and D" which was quality and quantity. After the analysis, description had been done to find out the causes of wellbore instability and what are its effects on drill performance. This chapter will describe the results of the analysis for each well.

4.2. Wells Design at Sharyoof Field:

During drilling stage of oil and gas industry drilling crew have met some of wells instability at this basin, as shown by Well Progression Chart at Say'un-Masilah basin that the well divided into 4 sections which is detailed at table below:

Table 4-1 Well Design for Sharyoof Wells

Phase	Position	MD/RT
$17^{1/2}$ " OH $13^{3/8}$" CSG	Top of Harshiyat	849 m
$12^{1/4}$" OH $9^{5/8}$" CSG	Weathered Basement	2788 m
$8^{1/2}$" OH sc 2-3-4	Basement	N/A
6" OH sc 2-3-4	Basement TD	N/A

4.3. Drilling Problems analysis at Well "A"

Compared with other wells as usually problems initiated as fluid losses during drilling, partial losses and in some cases it occurs stuck drill string. Problem in well A began when they did drill with aerated mud from 294 m to 328 m, there was a lost circulation so they mixed and pumped heavy LCM pill and continue drilled to 358 m, after connection observed partial returns, continued to drill blind with water and adding 1 1/2 T LCM/hr. pumped every single 10 m3 Hi-Vis bentonite with M-1PACR, after that observed partial/full returns.

Observed drilling break at 270m (top Sharwayn) which composed of Massive Shale interval. Here they was supposed to do checking for flow at this depth as routinely performed in drilling wells worldwide after drilling break to tells either stuck pipes will happen or a kick is in progress but they continued drilling and circulating with observed losses, they pumped LCM and drilled from 294 m to 328 m. Lost returns and as we said they used mud weight 1.030 SG, this is not in the aerated mud safe range that has designed in drilling program which is 1.04 SG as minimum and 1.09 SG as Max, so this may cause poor hole cleaning which can lead to stuck pipe…However they continued drilling from 328 m to 358 m after connection observed partial returns and restarted circulation. while they drilled blind from 294 m to 381 m they had heavy losses and ROP increased from 14.2 m\hr. to 17.4 m\hr. those were a primary causes of differential sticking even they pumped every single 10 m3 Hi-Vis bentonite but this did not help and as a result of the actions they have taken a string stuck. They worked on free string. Fire Jar 4 times after that it was not possible to Jar again. Work String up and down with circulation and without circulation but negative. They Lose bit, bit sub and bottom part of shock sub in hole.

As a last solution they make cement plug #1 and #2 and drilled 17 1/2" side track. While drilling 12 1\4" phase at 2829 m ROP decreased from 4 m\hr. quickly to 0 m\hr. While pull out of hole from 2829m to 2442m there was Tight hole at 2442m, they pumped out from 2442m to 2410m with 2700lpm/2350psi. Hole packed off on connection due to the settled cuttings which resulted by the inadequate hole cleaning so when they moved string down from 2410m to 2500m. Regained circulation and pumped 7m³ Hi-vis and circulation hole clean with 2700lpm. Approximately 4m³ cuttings and Cavings (90%) over shakers when pill on surface. After that start pull out of hole Pumped out from 2500m to 2264m with 2700lpm/2350psi. Hole packed off on connection. Worked string down from 2264m to 2315m.regained circulation and circulated bottoms up at 2700lpm/2350psi. Approximately 3m³ cuttings and Cavings (90%) on bottoms up. Pumped 10m³ Sun sweep to clean hole and circulated and raised mud weight from 1.20sg to 1.23sg. Flow check at 2829m. Pull out of hole from 2829m to 2747m. After that the first thing they back reamed from 2747m to 2503m. Worked pipe up and down, regained circulation and rotation and got pipe free. The second thing is attempted to

Pull out of hole on elevators but hole packed off and string got stuck several times. The third thing happened during back reaming found washout in top single of stand#82 only small amount of Cavings. Pull out of hole on elevators from 2210m to 1780m. Tight spots at 1900m and 1850 m, max over pull was 60Klbs, next that pull out of hole from 1780m to inside shoe at 850m. Flow check. Pull out of hole from 850m to surface. Flow check at BHA. C/O Bit. Run in hole with BHA to 137m. Slip and cut drilling line. Replaced loose nuts on brake pads and finely drilling continuous to target without problems.

Table 4-2 Mud Properties and Drilling Parameters in "Well A"

Mud Properties	
Parameters	**Value**
MW (Sg)	1.10-1.22
Funnel μ (Sec)	45-60
YP (lbs./100ft^2)	25-30
YS	>12
Filtrate (CC/Min)	4-5.5
Gels	ALAP
PH	9-9.5
Drilling Parameters	
Parameters	**Value**
Flow Rate (Lpm)	2900-3100
WOB (Tons)	6
RPM	135-140

4.4. Drilling Problems Analysis at Well "B"

While drilling stage at well C drilling crew meeting wellbore instability as follow:

Problems start with some fluid losses to trip tank, losses increasing to total losses at various depth 1526m, 1538m, 1039m… they tried to cure it by fill up through kill line with 34.77m3 mud with 1.18sg, pumped Barolift followed by 16m3 mud and Hi-Vis pill. again well in loss spot LCM, All of LCM was useless so they tried the another solution by spot cement slurry to perform 1st cement plug, they washed down from 1380m to 1538m tag top of cement at 1538m. No returns. Again prepare cement slurry and spot it to perform 2nd and 3rd cement plug. They washed down till tag top of cement at 1488m. No returns. which result with them to prepared cement slurry to perform 4th cement plug job, losses decreased gradually, at 1422m lost return again.

The consequence of already problems have stimulate other problems, Tight spot (Hole) which happened at different various depth at 1671m, 1629m, 1614m, 1606m, 1585m, 1578m, 1572m, 1579m, 1531m, 1496m, 1526m, 1444m, 926m, 1022m and 1000m. 1317m, 1269m, 1265m. Tight hole from 1467m to 1192m and from 1063m to 980m.

Note that tight hole usually observed across sections containing reactive clays, which result due to the swelling of the formation so depending on the correlate already mentioned depth with lithology column it shows that the levels of tight spot happened across the Harshiyat formation which composed of Sand, sticky clay and siltstone. But the problem doesn't stop with just tight spot improved to… As usually around the world that when they encountered tight spot they should conditioned drilling fluids and hole to continued drilling otherwise they will get pipe sticking.

Tight spot improved to pipe sticking with mechanical mechanism type at 1422m success freeing to 1415m and at 1375m which stop Pull out of hole at this depth they tried these remedial actions to retrieve drill pipe applied torque, spot LCM to cure losses. No returns. tried jarring and stretch test at 700m to reactivate string movement no rotation no jarring can't move up or down and no free point indictor tool (FPIT) response. Repeat stretch test again no FPIT response. At the end drill pipe was cut off at 1292m, the problem finished with run in hole cement stinger to perform 1st abandoned cement plug job.

Second pipe stuck at 1052m, 1047m, 1040 Work on stuck with Max Pull Up weight 450 klbs and Max torque 20 klb.ft. Firing Jar-Up, Pump Low-Vis/Hi-Vis Tandem pill, excessive quantity of materials on screens (LCM, formation cuttings). Hole clean. No losses. No progress. Running severing tool with explosives. Position severing tool at 998.9m. Fire the tool, got good indication.

The third one stuck happened at 1525m and get free, just like the already sticks occurred in Harshiyat Formation but this one solved and freeing pipes with these procedures, no Pump Out. Pull out of hole BHA from 1467m to 869m with max. overpull 50 klbs.

Can't to Run in hole with BHA from 866m to 1710m. No drag observed. Wash and ream down from 1710m to 1760m. Hole fill from 1730m. Hard reaming from 1746m to 1760m. Drill 12¼" hole from 1760m to 1911m. Drill 12¼" hole from 1911m to 2050m. Pump pill with Barolift, followed by mud and Hi-Vis-pill. Circulate hole clean. Cuttings increase on shaker by 35%. Flow check, well static.

The causes which we think were behind this instability and consequence problems are:

Due to the excessive length of this section in this well that reach +1550m as well as the high value of the physical properties (Permeability and porosity) of' HARSHIYAT" formation as well as its nature in containing fractures which give a chance to fluids invasion deeper and generate bigger problems which initiated as fluid losses as you read and result with wellbore instability which hence end with pipe stucking.

From sand granulometry field studies, it appears that the southern part of the field, is the only area with various layers of conglomeratic sand in the Harshiyat formation. Due to their high porosity and the important differential pressure while drilling, mud-cake in front of these conglomeratic layers may induce restriction (under gauge intervals). While tripping, the risk of encountering tight zones is considered high. Heavy losses to no return appear directly after removing the mud cake inducing bore-hole instability and pack-off which with it we can't pull pipes up. Which resulted due to the inadequate, insufficient hole cleaning.

While exposing new high permeable, porous formation and waiting allot of time to end this section the fluid gets enough time to fill formation and filtering in it as much as they late with drilling till result with new complicate consequence like formation swelling, poor hole cleaning and the instability of the formation at all which will meet. So with this well due to the various total losses depths the cleaning of hole is poor and the swelling of the formation is becoming greater gradually as fluid keep in loose which gradually result with tight spots at various levels in section 12-1/4" finally and due to all of the previous problem the biggest one will find out Pipe Sticking which cured by primary procedure, So they missed the Yield point value to be the correct one to remove and transport the cuttings to the surface the result was poor hole cleaning and result pipe sticking.

Table 4-3 Mud Properties and Drilling Parameters in "Well B"

Mud Properties	
Parameters	**Value**
MW (Sg)	1.10-1.22
Funnel μ (Sec)	48-60
YP (lbs./100ft^2)	28-32
YS	>12
Filtrate (CC/Min)	4-5
Gels	ALAP
PH	9-10
Drilling Parameters	
Parameters	**Value**
Flow Rate (Lpm)	2900
WOB (Tons)	6-14
RPM	100-120

4.5. Drilling Problems Analysis at Well "C"

As other wells while going through some of formations in this well they encountered wellbore instability and drilling problems at various and different depth and layers, which correlate depending on well lithology column such as:

Harshiyat formation that act the basic causes that lead to these losses due to its high porosity and permeability, at this Harshiyat formation which composed of sand, sticky clay and shale while back reaming from 1475 m to 1445 m with 2400 lpm, 130 Rpm, max torque 15Klbf, they got Total losses. As well as at depth 1385 m, 1184 m, also occurred Total losses, no annular level.

There was Formation losses 450 m³ at depth 1556m. To cure these losses, they pump in annulus 10 m3 LCM fine and medium, Pump 20 m3 LCM inside string fine and medium. No visible level in annulus, Pump 30 m3 LCM + KCl mud contain LCM (fine, medium, coarse) thru kill line at 500 lpm, Continue Mixing KCL Polymer Mud 1.22 sg with full parameters, Mixed LCM pill with MICA (f, m, c) 300 kg/m3. Used Dextrid, PAC LE and PAC RE to control Fluid Loss, Use Caustic Soda to maintain PH (9 - 9.5), Pump and spot Losses pill. Due to the unconsolidated formation, and due to exist of clay materials and shale that absorb the drilling fluid, and occur wettability, can be easily fractured with overloaded annulus or pack-off, resulting in severe / total losses and because this loss and the resulted mud cake and swelling occur by it, that reducing the hole diameter and making it difficult to run the tools in and out of the wellbore, as well as the poor cleaning process of wellbore which resulted due to the insufficient Yield Point values to hold and transport cuttings to surface all previous causes leads to tight spot at different depths at 901 m, 920 m, 931 m (stuck), 938 m, 949 m, 956 m, obstruction at 927m with 20 Klbs, From 2895 m to 2879 m, at 2623 m, 1913 m, 1884 m, 1585 m, 1452 m with max drag 25 Klbs, at 2900 m, 2584 m, 2441 m and 2342 m with max drag 50 Klbs.

To cure these tight spot, they ream down from 2885 m to 2950 m with Flow 2480 lpm, SPP 2950 psi, WOB 2-5 klbs, Rpm: 50 / Torque: 2-4 klb.ft.

Pump 7 m^3 Hi-Vis with Barolift followed by 26 m^3 mud and 7 m^3 Hi-Vis pill. Circulate hole clean with 2360 lpm at 2980 psi. Work on drill string with max over pull 50 Klbs. String stuck at 2883 m, tried to establish circulation - low flow. Back ream and ream down, string free and established full circulation. Attempt to Pull out of hole on elevator from 2874 m, with max over pull 50Klbs - no success. Pumping out from 2874 m to 2637 m with 0-5 Klbs, 2400 lpm, 2800psi. Caving on shakers in traces (no changed).

Pull out of hole at 1449m on elevator, observe lost level in annulus. String stuck, free down. Run back and start back reaming from 1475 m to 1445 m with 2400 lpm, 130 Rpm, max torque 15Klbf, Attempt to wash down, string plugged. Pull out of hole to casing shoe and attempt to pump without success.

Wash down with 3½" cement stinger BHA from 863 m to 941 m, several times tried to pass with washing and reaming, increase in pressure and drag -well show tendency to pack-off Hole under gaged, hard reaming - no possibility to run on elevator- No losses.

Pump 2 x 7 m3 Hi-Vis pill and circulation hole clean prior to Pull out of hole. Excessive amount of cuttings on shakers with pills.

Table 4-4 Mud Properties and Drilling Parameters in "Well C"

Mud Properties	
Parameters	**Value**
MW (Sg)	1.10-1.22
Funnel μ (Sec)	48-60
YP (lbs./100ft^2)	28-32
YS	>12
Filtrate (CC/Min)	4-5
Gels	ALAP
PH	9-10
Drilling Parameters	
Parameters	**Value**
Flow Rate (Lpm)	2900
WOB (Tons)	6-14
RPM	100-120

4.6. Analysis for Well "D"

In this well the problem starts at phase 17-1/2'' with some of losses improving to bigger problem Stucking drill string as happening with the other wells A, C &D. As follow:

Drill 17 3/4" hole from 58 m, 225m to 331m. well in loss. Blow well at 331m, pull out of hole and lay down cement BHA run in hole to 320m. pressure test lines at 1500 psi as a usually test ok. Pump 1st cement plug. Wait on cement, RIH cement stinger and tag top of cement at 272m (formation Mukalla) attempt to establish circulation no returns. to cure losses, they keep pumping various cement plugs in varying depth range from 270m to 331m. Rig Up Equipment to Dump Gravel Downhole: Gravel Volume Dumped 3m^3 (Theoretical Top at 250m). Run in hole and tag TOC at 160-Establish Circulation at 2500LPM, 2100SCFM: return ok – Pull out of hole and L/D Tubing. Wait on cement. Make up and Run in hole BHA. Drill Out Cement to 281m. (R1) -

Total Losses from 269m. Pull out of hole and Rack Back BHA. Pump 3m^3 Gravel. Set Cement **Plug #12.** Pull out of hole Stinger at 125m - Flush Tubing. Wait On Cement. Run in hole and Tag Top of cement at 164m Pull out of hole and L/D Tubing which we think was resulted due to drilled operation get through formation Sharwayn and Mukalla. After that they got the main event circulation Break at 440 m/RT - String free prior circulation, stuck after-No rotation and Indicator SPP difference between 600-800psi to 450-800psi - Work pipe until free. Back ream with 17"1/2 BHA from 440 m to 390 m/RT. Pull out of hole 17"1/2 BHA from 390 m to 180 m/RT. When operation was drill vertical section return from 437m to 757m (Harshiyat formation is a combination of clay stone and sand stone). Pump Hi-Vis. Pull out of hole 17"1/2 BHA from 757 m to 470 m/RT - Tight hole (is usually observed across sections containing clays or salt. The swelling of the clays results wellbore diameter eventually causing increased drag when pulling out hole).

About phase **12-1/4''** they encountered less problems compared with other wells:

While initiating diameter 12-1/4" ream from 1295 m to 1314 m - lost circulation at 1314m. Ream and pump lost circulation material (LCM) to 1343m Pull out of hole to surface. Change elevators, run in hole from 870 m to 1736 m, On the second day of loss circulation, Rig Up and pressure test cementing lines at 2000 psi for 5 min – OK. Cement **plug#14** at 1692 m. Wait on cement. Run in hole and tag top of cement at 1511 m. Rig Up and pressure test cementing lines at 2000 psi for 5 min - OK, pre-job safety Cement **plug#15** at 1507 m. Wait on cement. Run in hole and tag top of cement at 1348 m Circulate 3000 stokes-no returns. to cure losses, they keep pumping various cement plugs in varying depth range from 1316 m to 1736m. After 4 attempts of pumping cement plugs was tested Circulate at 1311 m (SPP 450 psi, 2000 lpm) - full returns. Pull out of hole and rack stinger. Change elevator, Make Up BHA and Run in hole to 1304 m (fill pipe at 867 m and 1304 m). Wash to bottom, drill out cement to 1336 m. Continue drilling to the end without other problem.

Table 4-5 Mud Properties and Drilling Parameters in "Well D"

Mud Properties	
Parameters	**Value**
MW (Sg)	**1.10-1.14**
Funnel ***μ*** (Sec)	45-60
YP (lbs./100ft^2)	**25-39**
YS	>12
Filtrate (CC/Min)	4.8-7.2
Gels	ALAP
PH	9-9.5
Drilling Parameters	
Parameters	**Value**
Flow Rate (Lpm)	2900-3100
WOB (Tons)	5-15
RPM	100-160

4.6.1. Mud System for well "D"

4.6.1.1. Type of mud:

KCl / Polymer / Soltex

4.6.1.2. Mud properties:

Table 4-6 Mud Properties for Well "D"

Mud Weight:	1.10 - 1.22 SG
Funnel Viscosity	45 to 60 sec
Yield Point	25 – 30 lbs/100sqft
Yield Strength	>12 lbs/100sqft
Gels	As low as possible
PH	9 to 9.5
Filtrate	4 to 5.5 cc/30mn
KCL	60 g/l

4.6.1.3. Mud composition:

Table 4-7 Mud composition for Well "D"

Drill water	1 M^3	800 M^3
Caustic soda	0.5 Kg	1 MT
Bentonite	25 – 40 Kg	32 MT
KCl	50 Kg	24 MT
Hibtrol HV	1 -2 Kg	2.0 MT
POLYSAL	6 – 8 Kg	8.0 MT
Hibtrol LV	4 – 6 Kg	5.0 MT
XC Polymer	1 – 2 Kg	2.0 MT
SOLTEX	15 - 30 Kg	16 MT
Soda Ash	According to hardness level	2 MT
Radiagreen EME	0.5 %	6 M3
MI-Cide	0.01 %	2 M3

CHAPTER FIVE

5. Conclusion, Recommendations, and Limitations

5.1. Conclusion

After the analysis for 4 wells at Sharyoof field it can be conclude as following:

- 30 % of the total NPT occurred due to unexpected events such as wellbore instability, drilling fluids losses and stuck pipe.
- Harshiyat formation was the interval that they face most of the problem because its component which contain sandstone and interbedded shaly layers.
  - Due to their high porosity of conglomeratic sand in the Harshiyat formation and the important differential pressure while drilling, mud-cake in front of these conglomeratic layers may induce restriction (under gauge intervals). While tripping, the risk to encounter tight zones is considered high. Heavy losses to no return appear directly after removing the mud cake inducing bore-hole instability and pack-off.
  - The incompatibility drilling conditions in Harshiyat with the Sarr formation resulting pack-off. Due to The Harshiyat formation contain almost of Sand, Shale and Sticky clay which considered unconsolidated formation, can be easily fractured with overloaded annulus or pack-off, resulting in severe / total losses. Comparing with Sarr formation which contains of Calcareous - Dolomitic that considered unstable formation, heavy caving tendency.
- The main problem was wellbore instability which occurs due to many reasons that can be summarized as following:
- Length of $12^{1/4}$'' section which reach 1500 m. This length makes the water base mud connect with the shaly formation for a long time which led to hydration process to happened.
- Inefficient mud system that used at well A, B, and C.
  - Mud system that had used at well D reduced the problem comparing with the other well. It has different properties form the previous such as: lower mud weight and higher cutting removal property (YP).
  - Drilling parameter has direct impact on the occurrence of the problem such as WOB and RPM which have higher values at well D more than A, B and C.

- The casing design and drilling fluids were the main causes of the problem which recommended to be edited.

5.2. Recommendation

1. Re-Design for the wells.

   Casing design should be change as following:

Drill the hole with $17^{1/2}$ inches until the top of Harshiyat formation and set casing at that section. After that, drill with $12^{1/4}$ inches bit until top of SAAR formation to continue with $8^{1/2}$ inches from top SAAR until bottom of Kuhlan formation (Top of Basement). The basement should be drilled by $6^{1/8}$ inches' bit.

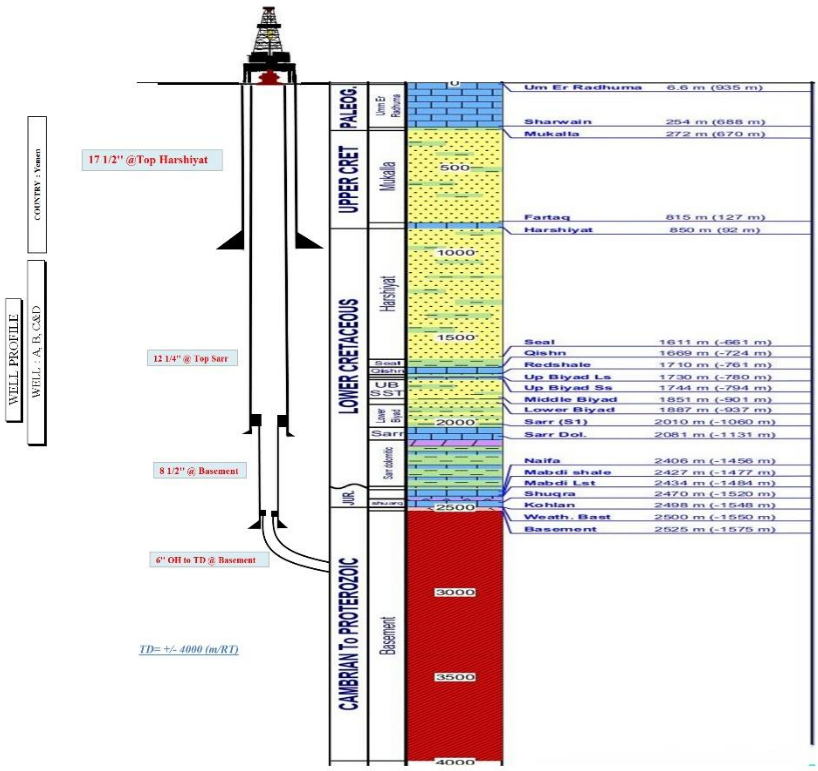

Figure 5-1 Recommended Casing Design

2. During drilling 12¼" phase section special care should be paid to maintain good drilling fluid Rheology, and hydraulics to ensure efficient hole cleaning.
3. A good drilling practice should be applied to control the specific ROP and tripping procedures for 12¼" phase section to avoid pack-off.

4. Trip out of hole without back reaming if possible and always start pump slowly to gradually break mud gel.
5. Drilling pipes must be usually move up and down as they suppose use the spiller drill collar type.
6. Change fluid properties (Mud System)
   - Start this phase with new KCl/Polymer mud at 1.10 MW using 80kg/m³ Marble fine and adjusting with Barite. Mud Weight shall be adjusting with Marble Fine all along the section. The system will be treated with 60 kg/m3 KCL at the beginning of the section and maintained while drilling till TD.
   - Moreover, Bentonite will improve the overall rheology of the mud and provide good progressive gels. Addition of Bentonite should be adjusted while drilling to maintain a CEC in the range of 35 – 40 Kg/m3.
   - Hibtrol-LV and Polysal will be added to the active system in the ratio 1:2, to control the filtrate at +/- 5cc.
   - Amount of Polysal will be reduced then completely replaced by Hibtrol-LV by the end of the Harshiyat section.
   - Hibtrol HV will be added to provide the primary viscosity of the mud in addition to the fact that it also offers some kind of anionic encapsulation.

5.3. Limitations

1. The Mechanical stress of Harshiyat formation stress couldn’t be analyzed, due to absence of sand granulometry studies.
2. Due to unavailability of financial data, difficult to determine the impact of the drilling well cost increases related to the borehole instability problems in Say’un-Masilah Basin.
3. Absence of drilling fluids lab to examine the recommended mud type led to put the recommendation according to previous studies.
4. Difficulties while gathering the data led to delay in accomplishing the project on time.

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