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Design of Loss Preventive Materials With Help of Geomechanics Modelling

تصميم المواد المانعة للفقدان بمساعدة النموزج الجيوميكانيكي

Project submitted in partial fulfilment of the Requirement for the Bachelor of Engineering (Horns) Degree in Petroleum Engineering

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الإستهلال

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿ أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ ۗ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ ۗ إِنَّمَا يَتَذَكَّرُ أُولُو الْأَلْبَابِ ﴿٩﴾ ﴾

سورة الزمر

صدق الله العظيم

قال رسول الله صلى الله عليه وسلم :{ ان الله وملائكته واهل السموات واهل الارض حتى النملة فى جحرها وحتى الحوت فى البحر ليصلون على معلمى الناس الخير } .

الإهداء

الحمد لله و كفى و الصلاة و السلام على الحبيب المصطفى و على أهله و من وفى ... أما بعد:
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Abstract

During drilling different layers with different lithology and mechanical properties where the drilling process encounters many wellbore instability problems specifically in weak formations which required different mud weight and rheological properties to be used, the easier method is to separate between this layers by using casing, but by this way drilling will end up using many casings in single wellbore which in turn appears to be not economic solutions, which lead to search for an efficient and economic solution for that problems and the Loss prevention materials (LPM) are considered one of the best ways to protect weak formations due to their economic quality compared to other methods , and to apply the LPM should know the wellbore instability problems, by application of geomecanical Earth model that used to give the mechanical properties (rock strength, horizontal stress , wellbore instability analysis) that used as effective tool to know and detect all the risks that can be faced, which helps to determine the suitable mud weight without cause a problems for any zone, to provide the data that required for create a Loss prevention materials Design to protect the weak formation by determined the (Fracture width and particle size distribution) to select the loss preventive materials(LPM) concentration for each weak zone to protect it and avoid the damage by the economic way .

التجريد

أثناء حفر طبقات ذات خصائص صخرية و ميكانيكية مختلفة , تواجه عملية الحفر مشاكل كثيرة متعلقة بعدم استقرار البئر خاصة في الطبقات الهشة حيث انها تحتاج لاستخدام سائل حفر ذو خصائص و كثافة معينة , و أفضل طرريقة للفصل بين تلك الطبقات يتم بواسطة استخدام انابيب التغليف , و لكن بهذه الطريقة ستنتهي عمليات الحفر باستخدام العديد من أنابيب التغليف في البئر الواحدة و بالتالي فهي ليست بالحل الاقتصادي . و من هنا تاتي الحوجة لحل اقتصادي و ذو كفاءة عالية في حل تلك المشاكل , وتعتبر المواد المانعة لفقدان سائل الحفر(LPM) إحدى الطرق الفعالة لحماية الطبقات الضعيفة من الانهيار وفعاليتها تكمن في الجدوى الاقتصادية مقارنة بالطرق الاخرى , و لتطبيق (LPM) يجب معرفة مشاكل عدم استقرارية البئر باستخدام النموذج الارضي الجيوميكانيكي (GEM) وهو عبارة عن نموذج يستخدم لحساب الخصائص الصخرية للطبقات مثال (قوة الصخر – الاجهاد الافقي – تحليلات عدم استقرارية البئر) , حيث يتم اعتباره كأداة فعالة في معرفة و كشف المخاطر التي يمكن أن تواجه عملية الحفر , كما أنه يساعد في تحديد أفضل كثافة لسائل الحفر ليتناسب مع الطبقات بدون احداث مشاكل لها ولذلك لابد من الحصول على البيانات التي تستخدم في حسابات تصميم (LPM) من اجل حماية الطبقات الضعيفة من الانهيار و ذلك يتم من خلال حساب (عرض شق الكسر – توزيع أحجام الحبيبات داخل الشق – اختيار تركيز LPM مناسب لكل جزء ضعيف من الطبقة لحمايتها من التضرر) .

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ρ_b	Bulk density of the formation
Δt_{comp}	Compressional slowness of the bulk formation
Δt_{shear}	Shear slowness of the bulk formation
K_{dyn}	Dynamic bulk shear modulus
G_{dyn}	Dynamic shear modulus
E_{dyn}	Dynamic Young's Modulus
V_{dyn}	Poisson ratio
R_{sp}	Ratio of shear and compressional slowness.
E_{sta}	Static Young's Modulus bulk shear modulus
U_{sta}	Static Poisson Ratio
G_{sta}	Shear Modulus (Static)
K_{sta}	Bulk Modulus (Static)
α	Poro-Elastic constant
$K_{skelton}$	skelton (dry) bulk module
C_o	Unconfined Compressive Strength
E_{dyn}	Dynamic Young's Modulus
K_{dyn}	Dynamic Bulk Modulus
K	Facies and zone based factor, default: 0.1.
TSTR	Tensile strength.
UCS	Unconfined compressive strength.
COH	Cohesion Strength
UCS	Unconfined Compressive Strength
FANG	Friction angle.
ISA	Integrated stress analysis.
σ_H	Maximum horizontal stress .
σ_h	Minimum horizontal stress.
σ_V	Vertical stress.
ε_h	Minimum principal horizontal strain.
ε_H	Maximum principal horizontal strain.
Q factor	Indicates the stress regime.
I_1 ,I_3	First and third invariables of the stress tensor.

η	Strength parameter .
σ_1 ,σ_2 , σ_3	Three principal stresses .
α	Biot's elastic constant
ν	Poisson's ratio
σ_h	Horizontal stress
σ_v	Vertical stress
P_p	Pore pressure.
${\sigma_H}^d$	Depletion maximum horizontal stress
${\sigma_h}^d$	Depletion minimum horizontal stress
Depletion	Pore pressure depletion percentage
Kappa	Factor indicating how depletion affects horizontal stresses.
${P_p}^d$	Depletion pore pressure.
Z	TVD .
PP_o	Pressure at sea floor.
K	Constant gradient (psi/ft).
Z	Depth measured from the sea floor.
R	Measurement value.
R_o	Measurement of sediments at the sea floor.
R_{norm}	Measurement value if the formation was normally pressured (it means the normal trend line).
P_{norm}	Normal pore pressure.
PP_{ref}	Reference pore pressure.
TVD_{ref}	Reference depth.
ρ_f	Fluid density.
g	Accelerator due to gravity.
P_m	Mud Pressure.
P_t	Pressure at fracture tip.
P_p	Pore Pressur.
W(x)	Fracture widths .
F(d)	Target cumulative distribution.
f(d)	Mix cumulative distribution.
LPMcon	LPM concentration.

Chapter 1

INTRODUCTION

1.1 Introduction:

Generally, wellbore instability is considering one of the main problems that engineers meet whilst drilling. The causes of wellbore instability are often divided into either mechanical such as : (failure of rock around the hole duo to high stresses, low rock strength, or in appropriate drilling practice) or chemical effects which cause formation damage due to interaction between the rock which is generally shale, and drilling fluid. These problems lead to bad consequences such as (formation collapse, stuck pipe that may require plugging and sidetracking, differential sticking, shale swelling, fluid influx and blowout). All these problems require high cost to be treated.

The drilling engineer is trying to make the wellbore stable by choosing proper mud weight, which has the ability to balance not high much cause fracture and not low much cause collapse. It is essential to estimate the true value of in situ vertical and minimum and maximum horizontal stress. The known values of in situ stresses and pore pressure certainly may be beneficial in detecting and preventing the occurrence of the instability of drilled wells. With information of these values the mud window for difference depths of the well is estimated and the appropriate mud density and overpressure zone for safe drilling in bore hole are also determined.

The aim of this research is to build geomechanical earth model use to calculate the mechanical properties (Elastic & Dynamic Properties) and strength of the rock as well as the wellbore stresses based on the in-situ stresses. Then, it predicts the breakout and breakdown pressure, Pore pressure, in addition to the fracture gradient. Through number of key parameters which required to come up with mechanical properties and geological discretion for all layers along the well. These parameters reveal weak and strong formations and differential sticking across intervals which have the potential risk of instability.

Drilling operation require selection of ideal mud that preferred to successfully prevent occurrence of lost circulation, these losses are result of induced fracture occurs when mud weight exceeds the fracture initial pressure thereby leading to total or partial losses into weak formation, and it is primary cause of non productive time during drilling process. In this research we applied wellbore strengthen technique/model which is lost preventive material (LPM), which is designed to seal and effectively increase fracture resistance allowing the operator to drill through a weak formation zone successfully with minimal to zero losses. In order to reach optimum LPM design and proper particle size distribution through the fracture will be achieved by number of parameters such as: (fracture width, hole diameter, fracture length, differential pressure) gained from well and rock data which obtained from geomechanical output data.

1.2 Problem statement:

The Drilling operation extends along the well, where layers of different properties are drilled. For hole sections containing both sandstone/carbonate and shale/mudstones, Mud weight has been selected should be balance between that required to prevent hole fracturing and that required to prevent hole collapse. If a balance cannot be achieved then an extra casing string should be consider. But if the well plan does not allow of an extra casing string, In addition to highly cost of casing which its usage will not be an economical solution. Then the well encounters many instability problems concerned with shale , and problems concerned with sandstone. These problems are the primary cause of disrupting drilling operations with inside the absence of enough and correct understanding of the mechanical properties of formations. One of the suggestion wellbore stability (SW) that can be accomplished is to treat the whole drilling fluid with lost preventive material (LPM) that are designed to seal and effectively increase formation strength with low cost compare to the other solution .

1.3 Objectives:

- Create a geomechanical Model that gives an geomechanical description (wellbore instability analysis) for the formations along the well .
- Display the zones that has potential risk of (Mud losses, Breakdown , shear failure or kick) .
- Provide the best rang for mud weight that can be used .
- Applying the Lost Preventive material (LPM) that are designed to seal and effectively increase formation strength .

Chapter 2

Historical Background and Literature review

2.1 Historical Background

2.1.1 Geomechanical Earth Model:

Geo-mechanical earth model is represent entering of data (measurements and models) exemplification the mechanical properties of rocks and fractures as well as the stresses, pressures and temperatures acting on them at depth. Engineers and geoscientific use it to proper know how the rocks deform, and occasionally fail, in response to drilling, completion and production operations. Rocks deform in a variety of ways in response to stress. Some rocks, such as granites, are stiff and strong; some, such as mudstone, which is weak, and some such as salts, with sufficient time can flow. An MEM provides information about mechanical behaviour and strength of the rock by using relationships between rock properties, induced deformations and ambient conditions. Because of the layered fabric of rocks or the presence of fractures, rock properties are frequently anisotropic, their properties are not the same in all directions as they would be with isotropic media . **(Thomas Bérard, 2017)**

Subsurface formation are subjected to three compressive stresses, vertical stress (σv) is due to weight of the overburden, this vertical load and forces transferred laterally together with tectonic forces give rise to unequal two horizontal stresses maximum and minimum horizontal stresses (σ_{Hmax} and σ_{Hmin}) . In strike-Slip fault regime, σv is intermediate between two horizontal stresses wellbore stability related issues could create serious problems in drilling and stimulation operations leading to increasing of non-productive time (NPT) and costs. These issues occur in highly deviated and horizontal wells, especially in active tectonics areas, where anisotropy elevated between the three principal stresses.

Wellbore stability is a function of how rock mechanically responds to stress re-distribution while drilling, rock may fails or yields depending on rock strength and stresses magnitude and orientation. The primary constituents of a geomechanical model are shown in Figure 1, three principal stresses, and formation pressure (Pp) and the rock mechanical properties and rock strength **. (osman hamid, 2018)**

The geomechanical modelling for reservoir involves detailed knowledge of :

a) In-situ stress magnitudes .
b) Pore pressure .
c) Stress orientation .
d) Rock mechanical properties .

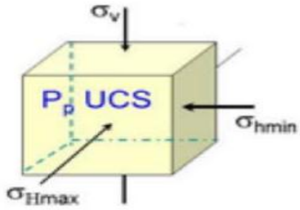

Figure (2. 1) : schematic showing key parameters of a geomechanical model.

Wellbore instability can be produce because of stress redistribution around the wellbore due to stress anisotropy and when the surrounding formation reach the failure point, in strike-slip regime fault, the stress distribution for a well drilled in a direction of the σ_{Hmin} can be give by the following correlation.

$$\sigma_\theta{}^{max} = 3\sigma_{Hmax} - \sigma_v - P_w - P_p$$ (Equation 2.1)

$$\sigma_\theta{}^{min} = 3\sigma_v - \sigma_{Hmax} - P_w - P_p$$ (Equation 2.2)

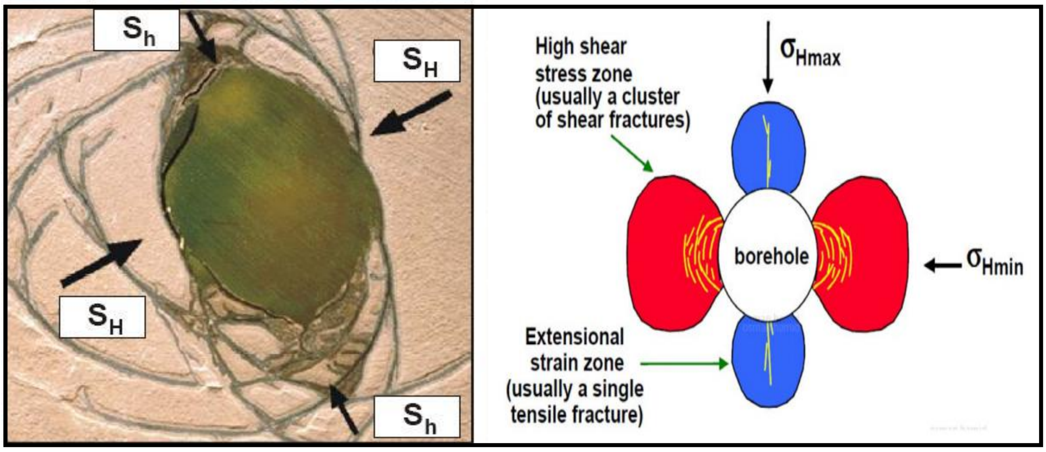

Figure (2. 2) : yielding type around vertical well bore

2.1.2 Wellbore instability :

The stability of the well is one of the most important factor that we are looking for before start to drilling any well to avoid the problems that can happened according to the instability of the well , and Before drilling the well the formation rock is in equilibrium state , when start the drilling process the equilibrium is changed and the well needs a new barrier to resist the forces around the well to keep it's stability . The drilling fluid is very important in order to prevent the instability problem which come from the normal stresses of the formation that occurs when the rock is removed while drilling. Since the equilibrium of the stresses is changed when the well is drilled, that change should be controlled . To have control of how these changes are occurring without resulting in any instability problems, it is important to have good knowledge about the strength of the rock in order to not damage the integrity of the rock during drilling by the proper selection of a drilling fluid density that balances the hydrostatic pressure to prevent the influx of formation fluids without exceeding the fracture initiation pressure of the exposed formations in the open hole .

Generally the Rock-Chemical Interaction (Shale) Instability is can cause alot of problems ,and In the Mechanical Wellbore Instability At low borehole pressures , the tangential stress is high which can cause a (Collapse) , and at high borehole pressure, the tangential stress goes into tension which can cause a (Fracture) , according to that the drilling fluid density should be balanced (not high much which cause fracture and not low much which cause collapse) and by using cage stress (particle bridging) or wellbore losing fluid.

The instability problem is represent very large part of the problems that occur in the well. Rather, it is the main reason for disrupting drilling operations in the absence of sufficient and accurate knowledge of the formation pressure , which may cause major problems that may lead to severe damage , Thus, reducing the possibility of these problems that lead to reduce the damage and cost resulting from maintenance and repair operations that occur due to stability problems , and by the wellbore stability module can calculates the mechanical properties and strength of the rock as well as the wellbore stresses based on the in-situ stresses ,and show which mud weight is better to be used while drilling the wells .

Wellbore instability prove itself in different ways like hole pack off ,excessive reaming, over pull, torque and drag, occasionally leading to stuck pipe that may require plugging and side tracking. This requires additional time to drill a hole, increase the cost of reservoir development significantly. In case of offshore fields, loss of hole is more critical due to a limited number of holes that can be drilled from a platform. Drilling an in gauge hole is an interplay of two factors : uncontrollable and controllable. **(Mohiuddin et al., 2007)**

unknown behaviour of rock is often the main cause of drilling problems, resulting in an expensive loss of time, sometimes in a loss of part or even whole borehole. Borehole instability is a continuing problem which results in substantial yearly expenditures by the petroleum industry (Bradley, 1978, Awal et al., 2001). As result, a major handle of the drilling engineers is preserve the borehole wall from falling in or breaking down. Detailed attention is paid to drilling fluid programs, casing programs, and operating procedures in drilling a well to minimize these costly problems.

Wellbore instability has become an increasing handle for horizontal and expanded reach wells, specially with the move forwards completely open hole lateral section, and in some cases, open hole build-up section through shale cap rocks. More recent drilling innovations such as clam drilling techniques, high pressure jet drilling, re-entry horizontal wells and multiple laterals from a single vertical or horizontal well often give rise to challenging wellbore stability question .

2.1.3 Lost Preventive Material (LPM) :

The loss of large volumes of whole mud to the formation (lost circulation) has historic been a basis cause of well control problems and high mud costs. Many drilling risks such as hole collapse, stuck pipe, and even blowouts have been the result of lost circulation. Lost circulation can occur naturally in formations which are cavernous, vugular, fractured, or unconsolidated or it can be the result of induced pressure. Proper pre-drill planning should allow for the determination of risks zones, optimization of drilling practice and the establishing of both preventative and remedial treatments. Here the term 'preventative treatment' also refers to the philosophy of wellbore strengthening. Induced fracturing is of particular handle when drilling into depleted zones. In these cases reservoir production has reduced the pore pressure leading to a commensurate reduction in fracture pressure. One approach of WS that can be accomplished is to treat the whole drilling fluid with Lost Preventive material (LPM) that are designed to seal and effectively increase formation strength.It is desirable to select a particle size distribution that will efficiently and quickly bridge the largest, medium and smaller pore size fractions because particle size appeared to be the most important variable for obtaining a fracture sealing response.

Lost circulation generally indicates to a complicated down-hole situation when wellbore fluids, such as drilling fluids and cement slurry, leak into pores, fractures or caves of subsurface formations due to a positive pressure difference during drilling, cementing and testing operations. Lost circulation not only delays operations, wellbore fluid losses fluid and damages the hydrocarbon reservoir, but also causes drilling accidents such as wellbore collapse, stuck pipe, blow-out, and even borehole abandonment, resulting in significant economic loss. Lost circulation is so complicated that relevant research involves multiple disciplines such as geology, rock mechanics, fluid mechanics, physical chemistry, and material mechanics .

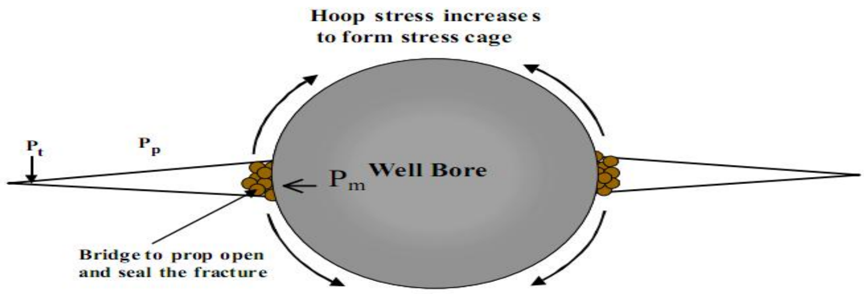

Figure (2. 3) : Stress cage concept

2.1.3.1 Lost Preventive Material Mechanisms

Fluid-loss treatments, are preventative or remedial (and here by implication wellbore strengthening methods are included based on LPM blends) fall into two main categories:

- Low fluid loss where the fracture or formation is rapidly plugged and sealed .
- High fluid loss where dehydration of the loss prevention material in the fracture or formations forms a plug that then acts as the foundation for fracture sealing .

Low-Fluid-Loss Treatments :

Low-fluid-loss treatments are either cement, chemical resin, particle-based, or a combination thereof. For the particle based treatments , the particle size distribution (PSD) is broad and designed to establish coarse-particle framework in the loss zones upon which finer and finer particles are incorporated to reduce fluid loss. One approach is to adopt a PSD that follows Ideal Packing Theory.3 This results in a weight- or volume-based cumulative PSD that is proportional to the square root of the particle size. The product blend should include very coarse particles to plug or bridge the largest openings in the Formation, be they fractures or pores.. Whether the formation openings are plugged or bridged, finer particles are also necessary to fill the voids between the coarse particles, and even finer particles are necessary to produce a tight filter cake, thus effecting a seal and fluid loss control Figure 4 . The distinction between plugging and bridging is not great. One definition is that plugging results when the D90 of the LPM is greater than the aperture of the formation openings; bridging results when the D90 of the LPM is less than ½ x the aperture. Low-fluid-loss treatments can be used in both low permeability (mudstone, shale) and high-permeability formations (sand, fractured or vuggy carbonates) .

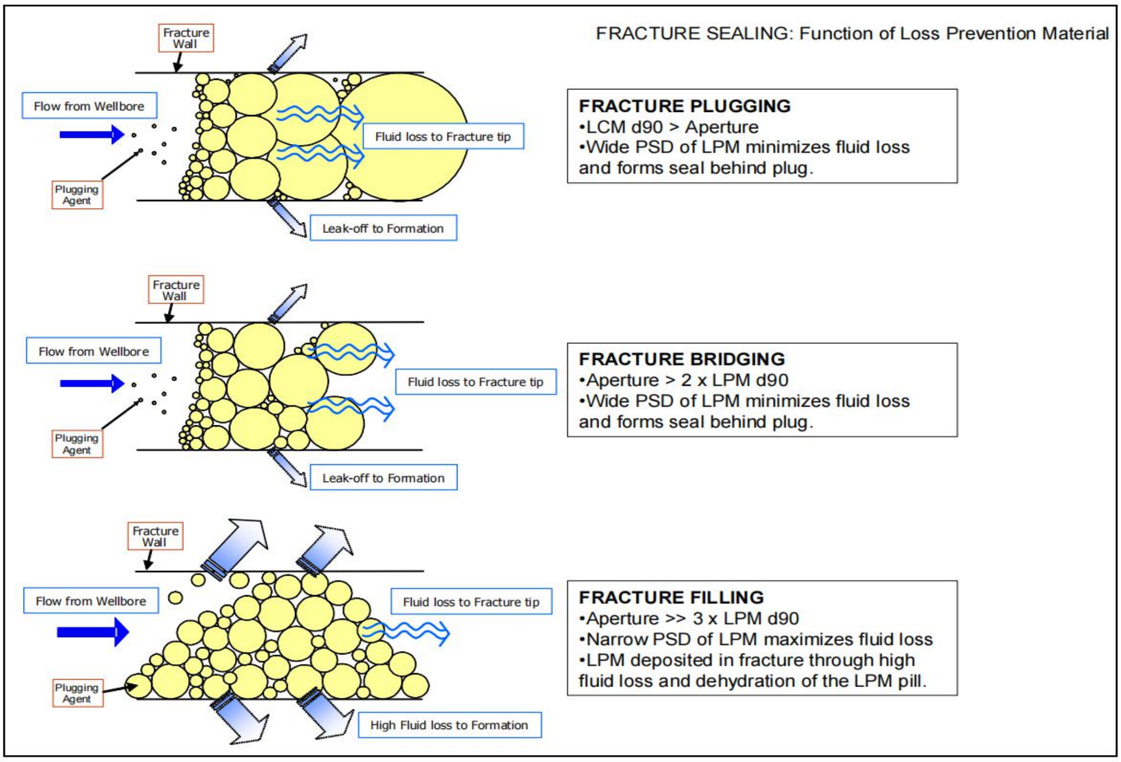

Figure (2. 4) : Fracture sealing function of loss prevention materials.

High-Fluid-Loss Treatments

High-fluid-loss treatments are generally particle based. Ideally, the particle size distribution is relatively narrow (uniform) in order to promote fluid loss. In relative terms, the particle size of the LPM should be smaller than the fracture opening. This is necessary to ensure the material enters into the fracture and is then deposited by a process of dehydration as the carrier fluid leaks-off Figure 4. The success of the treatment requires high fluid loss; thus, contamination by drilling mud or other fines-laden fluid can significantly impair its effectiveness. Therefore, it follows that this type of treatment is more suited to the spotting and squeezing of pill-based LPMs. The treatment may not be effective in sealing very wide fractures (> 2 mm) - excessive flow rates in such fractures may prevent the deposited material from completely plugging the fracture opening. In addition, very large volumes of material may be required. Under these circumstances, the high-fluid-loss treatment may be used to slow the rate of loss sufficiently to enable plugging by settable plugging treatments like cement or gunk. High fluid loss treatments can only be used in high permeability formations or fractured formations where there already is a pre-existing high fluid loss.

Drilling operation generally requires the selection of an optimum mud weight that is required to successfully prevent the influx of formation fluids into the well bore, although without exceeding the pressure required to initiate a fracture across the formation. Induced losses, which are a result of induced fractures occur when the mud weight exceeds the fracture initiation pressure therefore leading to a total or partial loss of mud into the formation. Such conditions can whatever be mitigated by the introduction of loss prevention materials (LPM) into the mud composition with the potential to bridge or seal the created fractures. Artificial neural network, a branch of Artificial intelligence has been applied over time successfully in various industries including the oil and gas industry. Artificial Neural network (ANN) is being applied in this work to predict the fracture width anticipating in different formations and to also determine the particle sizes of the loss prevention materials to be used over such intervals . **(okoro solomon, 2017)**

2.2 Literature Review

One of the study that related is highlighted to demonstrate the effectiveness of customized geomechanical solutions and It's discuses the implementation of geomechanics at a specific sub-surface condition to attain the best result . The study is pointed to where was a high risk for wellbore instability while drilling through highly stressed formation in minimum stress direction. The task was approached in a systematic way with a core objective of ensuring practical implementation of geomechanics findings, and follow the recommendations to mitigate wellbore stability related issues. And It was evaluated two options to prevent and mitigate wellbore stability, the first one is to low mud weights together with wellbore surveillance using real-time technolog, the second one is to use higher mud weights using sealing polymer and proper mud system formulation to avoid differential sticking . **(osman hamid, 2018)**

To analyse the stability of the hydrocarbon wells, it is necessary to determine the true value of in situ vertical and minimum and maximum horizontal stress. The known values of in situ stresses surely will be useful in detecting and preventing the occurrence of the instability of drilled wells. In the south pars field, Iran the value of in situ stress is determined for two wells drilled. With information on the in situ stress and the pore pressure, the mud window for different depths of this well is determined and the appropriate mud density and overpressure zone for safe drilling in bore hole are also determined. It is possible to determine the in situ stresses using well logs for a well in. And the proper mud weight is selected by using the pressure gradient.

Conventional well logs namely gamma ray, sonic velocity; shear velocity and density are use as raw data for estimation of pore pressure and Sv. Caliper log and bit size are calibrated to remove possible washout zones. In this study the pore pressure was estimated using the Zhang method and the results were compared with RFT data for case study in south pars field. The results indicate that the pore pressure is estimated. Upon entering the over pressure zone at studied wells, the amount of vertical stress does not change, therefore the amount of vertical stress depends only on the density of the overlaying rocks and fluids. But the minimum and maximum horizontal stress will change. In the overpressure zone, the mud window is reduced which makes it difficult for the reservoir engineers to choose the appropriate mud density. For the interval above the overpressure zone (depth of 2200 m), a mud density of 8.33 ppg should be chosen; however, in the overpressure interval, the drilling mud density should be increase to 8.8ppg in order to overcome the increase in pore pressure. **(Farshid Mousavipourl, 2020)**

Wellbore stability problems are common when drilling high angles well in deep basins .The case of wellbore failure depends on various parameters such as the in-situ stresses ,pore pressure rock properties ,formation strength ,mud weight ,well profile. According to the theory of rock mechanics drilling results alteration in the stress field when bolster rock mass fails .circumferential and radial stresses are generated which produce an additional shear stresses .When the value of shear stress exceeds the rock strength , failures takes place in the borehole. To avoid well bore failures ,good understanding of rock mechanical properties is crucial for designing optimally-stable borehole trajectories and mud weight values. Generally in the negative margin basin setting Sv remains dominant stress and Smin and Smax are close to each other hence different tangential stress acting on the well bore is less . **(Samit Mondal , 2011)**

Pore Pressure prediction and stress profiles are significant parameters for (1)well planning, materials and costs estimates for construction of a safe, modern well including logistics, operations planning and procedural guidelines, and (2) prospect definition, financial risk assessment, overall project applicability and basin exploration.being a young tectonically active waistband rich in hydrocarbon resources well bore stability becomes a main matter in exploration and production. Here we have estimated pore pressure (PP), vertical stress magnitude (S_v) and minimum horizontal stress value (S_h) from two wells located in the tectonically active upper Assam basin. **(Jenifer Alam, 2017)**

In Ula field A geological overview was made to see the geological perspective of it all. All the historical instability problems and mud weight was collected from previously drilled wells which was then put into a three-dimensional model. This three-dimensional model gave a good understanding of how the field was behaving, and look at the wells as an overall picture and not just one by one. The objective of this study was to make a model that could be used to design a good mud program for the new injector wells that are going to be drilled on the Ula field in the near future. It is important that the mud program is designed such that the instability problems will be as low as possible and reduce non-productive time due to wellbore instability. From a calculated collapse curve it is possible to find the minimum recommended mud weight that could be used when drilling the new well . **(Farshid Mousavipour, 2020)**

New zones in mature fields in nigeria is continue to be actively developed as operators strive to maintain depleting reserve, drilling activities in or near producing or previously abandoned reservoirs often encounter large variations in pressure gradient as depleted layers or low pressured zones are exposed during the drilling process. Zones with pressures inconsistent with the overburden are often encountered, if conventional drilling techniques are used, then the higher mud weight used to hold back the target interval may result in massive losses (lost circulation), differential sticking, sloughing, or collapsing formations in the lower-pressure zone. The researcher is reach to develop a modelling software and choosing a material can be applied in support of wellbore pressure containment and techniques to more accurately predict and optimize LPM selection. This work presents the approach of WS that can be accomplished with treatment of the whole drilling fluid with Lost Preventive material (LPM) that are designed to seal and effectively increase fracture resistance allowing the operator to drill through a weak formation zone successfully with minimal to zero losses . **(eric van oort, 2009)**

Various techniques have been developed over the years in the oil and gas industry to make the process of borehole construction more cost-effective and safe. The methods adopted in preventing lost circulation during drilling can be assorted into two broad categories :

Remediation techniques(Lost circulation materials), Prevention techniques (Wellbore strengthening materials, Drilling fluid selection, Best drilling practices). The prevention techniques focus on preventing the lost circulation from occurring during drilling operation. Best drilling practices involves implementing models (geo-mechanical) to calculate the risk of the occurrence of hole collapse or lost circulation, thereby incorporating techniques as casing while drilling, managed pressure drilling or expandable casing drilling. The drilling fluid selection involves the preparation of fluids with proper rheological properties for minimizing or curing lost circulation. In wellbore strengthening, lost circulation prevention is by adopting specially formulated and sized particulate materials in the drilling fluid that enter a fracture and control its propagation by sealing the fracture width, accordingly isolating it from the wellbore. re-mediation techniques uses lost circulation materials to hold the loss of mud into the drilled formation. The lost circulation prevention method used in this study is wellbore strengthening using loss prevention materials**. (okoro solomon, 2017)**

The study reported here had the objective to investigate the interplay between LPM, fluid loss and formation permeability in the plugging and sealing of fractures. Specifically, it was the intention to shed light on how fracture sealing is influenced by the PSD of the LPM relative to the aperture and also the distribution of flow between the fracture tip and the formation (fracture walls). The results of the study clearly show that the mechanism of fracture plugging, where a seal is formed at (or immediately adjacent to) the entrance to the aperture, produces the most competent fracture seal that are capable of withholding high mud pressures. This process requires that the LPM blend contains particles that are larger than the fracture aperture. Furthermore, the effectiveness of the seal appears to be sensitive to the relative concentration of larger particles such that equating the D100 of the LPM PSD to the fracture aperture is likely to produce a less effective seal than if the D90 was used. The mechanisms by which fracture filling and sealing occur – via dehydration and deposition of LPM within the aperture – are observed in the experiments. In these cases, the LPM contains only particles that are smaller than the fracture aperture. The maximum seal pressures are not as high as those obtained for fracture plugging and may be limited by the frictional resistance of the LPM particles that hold the bridge in place. Once the foundations of the seal are established, either through aperture plugging or dehydration and deposition of the LPM, the rapidty with which an effective pressure seal is established appears to be primarily controlled by the fluid-loss characteristics of the LPM where this is governed by the relative concentration of the finer fraction in the particle size distribution. This needs to be investigated further using different LPM concentrations, LPM formulations with higher fluid loss characteristics and porous plates with much lower permeability's. The experiments do not prove or disprove the concepts of wellbore strengthening as they were designed to test only the mechanisms of fracture sealing by the manipulation of the LPM PSD and fluid loss. Wellbore strengthening requires that the LPM that seals the fracture also props open the fracture, preventing it from closure, thus increasing the tangential stress (hoop stress) local to the wellbore wall. The apparatus that has been used in this study can also investigate the mechanisms of wellbore strengthening (fracture propping) and this is currently the subject of another laboratory study. **(N-kaggeson-loe, 2008)**

The increase in the pressure bearing capacity is critical for mitigation of lost circulation, and to do so the strength of the plugging zone should be increased via picking an effective evaluation method and choosing the proper particle size distribution (PSD). Therefore, in order to successfully investigate this process, the conventional evaluation tool of lost circulation should be improved for dynamic variation of fracture width to find the optimized plugging materials. This means, a new testing apparatus device capable of testing dynamic fracture width should be developed. Additionally, commonly used selection criteria of PSD are incapable of providing us with a continuous PSD curve since they only fulfill discrete PSDs. To overcome these two obstacles, a variety of continuous PSD models based on a new testing device and method are examined. Likewise, the impact of governing parameters and an optimized PSD selection criterion were studied with a specific lost circulation material (calcium carbonate) and concentration in a water-based drilling fluid. The experimental results demonstrate that the normal distribution model provides the best selection result while the delicate analysis indicate that the factors effecting pressure bearing capacity in a sequential order are: minimum particle size, standard deviation, maximum particle size and average value. Besides, the optimized experiments illustrated that the maximum particle size should be 1.3 times of the maximum fracture width and the minimum particle size should be 0.8 times of the average fracture width. Furthermore it, the average value should be equal to the optimal particle average size and the standard deviation should be 0.3 times of the particle average size. It was found that the optimized selection method results in the highest plugging efficiency analogy to conventional selection criteria. Collectively, the new device and optimal assessing approach would improve the prediction precision of pressure bearing capacity to select an appropriate PSD with different of fracture width in field operations. **(Samit Mondal , 2011)**

Chapter 3

Methodology

3. Methodology

The Geomechanical Well-bore stability model is use to calculate the mechanical properties and strength of the rock as well as the wellbore stresses based on the in-situ stresses. Then, it predicts the breakout and breakdown pressure, Pore pressure , in addition to the fracture gradient (mudloss, minimum horizontal stress, or maximum horizontal stress) using theoretical models , and then predict the proper range of mud wight to be used to avoid as much as we can the risk of (Breakdown , losses , kick , or shear failure area) .

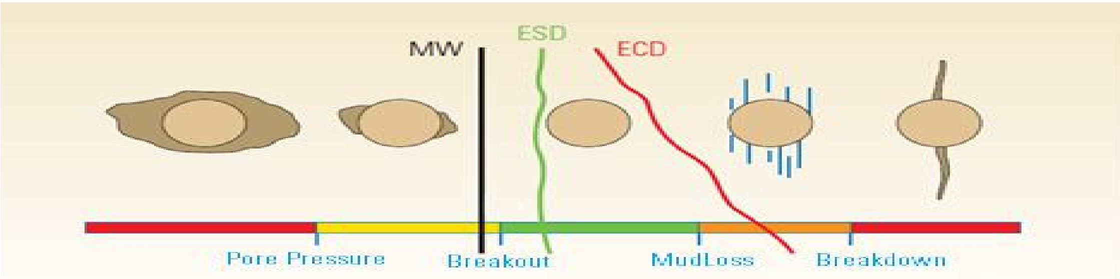

Figure (3. 1) : wellpore instability discription

3.1 Calculation Of The Mechanical Properties

3.1.1 Dynamic properties :

The Correlation :

- Isotropic Properties

The Output :

- Dynamic Young's Modulus
- Dynamic Poisson Ratio
- Dynamic Bulk Modulus
- Dynamic Shear Modulus

3.1.1.1 Isotropic Properties (for Dynamic Elastic Properties)

The model is to compute the dynamic modulus from sonic and density logs. It is based on the theoretical relation of sonic logs and the dynamic elastic moduli.

Theory :

Given the assumption of a homogeneous, isotropic, and elastic formation, dynamic shear and bulk modulus, G_{dyn} and K_{dyn}, can be computed by :

$$G_{dyn} = (\,13474.45\,)\frac{\rho_b}{(t_{shear})^2} \quad \text{(Equation 3. 1)}$$

$$K_{dyn} = (13474.45\,)\rho_b\left[\frac{1}{(\Delta t_{comp})^2}\right] - \frac{4}{3}G_{dyn} \quad \text{(Equation 3. 2)}$$

Where:

ρ_b ≡ bulk density of the formation (g/cm3).

Δt_{comp} ≡ compressional slowness of the bulk formation us/ft

Δt_{shear} ≡ shear slowness of the bulk formation us/ft.

K_{dyn} and G_{dyn} are in Mspi.

You can compute Dynamic Young's Modulus and Poisson ratio with Shear and Bulk modulus:

$$E_{dyn} = \frac{9G_{dyn} \times K_{dyn}}{G_{dyn} - 3K_{dyn}}$$ (Equation 3. 3)

$$V_{dyn} = \frac{3K_{dyn} - 2G_{dyn}}{6K_{dyn} - 2G_{dyn}}$$ (Equation 3. 4)

$$V_{dyn} = \frac{{R_{sp}}^2 - 2}{2{R_{sp}}^2 - 2}$$ (Equation 3. 5)

Dynamic Poisson ratio can also be computed from:

$$\mathbf{V_{dyn}} = \frac{\mathbf{R_{sp}}^2 - 2}{2\mathbf{R_{sp}}^2 - 2}$$

Where $\mathbf{R_{sp}}$ is the ratio of shear and compressional slowness:

$$R_{sp} = \frac{{\Delta t_{shear}}^2}{{\Delta t_{comp}}^2}$$ (Equation 3. 6)

3.1.2 Static Young's modulus :

The Correlation :

- John Fuller correlation

3.1.2.1 John Fuller Correlation (for Static Young's Modulus)

The Input :

- Young's modulus (Dynamic)

The Output :

- Static Young's modulus

Theory :

This model computes static Young's modulus from dynamic Young's modulus which is proposed by John Fuller. The correlation is based on a sandstone data set from the North Sea. The range of sand strengths (UCS) is mainly between 2000 - 10000 psi from about 20 samples. The correlation was built on triaxial core measurements of YME at 1MPa confinement and equivalent DSI log points in the same well.

Application :

It can be applied to sandstone as well as shale.

3.1.3 Other Young's modulus :

The Correlation :

- Static Poisson ratio
- Static bulk and shear modulus

3.1.3.1 Static Poisson Ratio Correlation

The Input :

- Poisson Ration

The Output :

- Poisson Ration (Static)

Theory :

PRs = PRd × PR multiplier - Unit of PR_multiplier, unitless.

Application:

The default value of PR multiplier is 1.0, then the static Poisson ratio is equal to the dynamic Poisson ratio.

3.1.3.2 Static Poisson Ratio Correlation

The Input :

- Young's Modulus (Static)
- Poisson Ration

The Output :

- Bulk Modulus (Static)
- Shear Modulus (Static)

Theory :

We can compute Static bulk and shear moduli with the theoretical equation:

$$\boldsymbol{G_{sta} = \frac{E_{sta}}{2(1 + v_{sta})}}$$ (Equation 3. 7)

$$\boldsymbol{K_{sta} = \frac{E_{sta}}{3(1 - 2v_{sta})}}$$ (Equation 3. 8)

Where :

$E_{sta} \equiv$ Static Young's Modulus

$U_{sta} \equiv$ Static Poisson Ratio

$G_{sta} \equiv$ Shear Modulus (Static)

$K_{sta} \equiv$ Bulk Modulus (Static)

3.1.4 Biot coefficient :

The Correlation :

- Krief porosity

3.1.4.1 Krief porosity (for Biot Coefficient)

The Input :

- Effective Porosity

The Output :

- Biot Coefficient

Theory :

This correlation was suggested by Krief. It assumes that you can estimate the skeleton (dry) Bulk Modulus of rock from the Effective Porosity .

You can estimate the skeleton (dry) Bulk Module of rock with the effective porosity and solid Bulk Module as:

$$\boldsymbol{K_{skelton} = K_{solid}(1-\phi)^{\frac{3}{1-\phi}}} \quad \text{(Equation 3. 9)}$$

Poro-Elastic constant **α** can be derived by:

$$\boldsymbol{\alpha = 1 - \frac{K_{skelton}}{K_{solid}} = (1-\phi)^{\frac{3}{1-\phi}}} \quad \text{(Equation 3. 10)}$$

In this model, $\mathbf{K_{skelton}}$ and $\mathbf{K_{solid}}$ are only used for derivation and not for calculation.

Note: The range of effective porosity is: f <= 0.35

3.2 Calculate the strength of the rock :

The Rock strength process computes the rock strength properties to build the rock strength criteria in the earth geological module , and this properties is can classified at the follow :

3.2.1 Unconfined Compressive Strength (UCS) :

The Correlation :

- Coates Denoo

3.2.1.1 Coates Denoo Correlation (for UCS)

The Input :

- Young's Modulus (Dynamic)
- Poisson Ratio (Dynamic)
- Shale Volume

The Output :

- Unconfined Compressive Strength

Theory

$$C_o = 0.0866 \times \frac{E_{dyn}}{C_{dyn}}(0.008V_{sh} + 0.0045(1 - V_{sh})$$ (Equation 3. 11)

Where C_{dyn} is the Dynamic Bulk Compressibility, can be expressed as:

$$C_{dyn} = \frac{1}{K_{dyn}}$$ (Equation 3. 12)

Where

C_o ≡ Unconfined Compressive Strength (Mpsi)

E_{dyn} ≡ Dynamic Young's Modulus (Mpsi).

K_{dyn} ≡ Dynamic Bulk Modulus (Mpsi).

3.2.2 Friction angle :

The Correlation :

- Friction Angle from GR

3.2.2.1 Friction Angle from GR (for Friction Angle)

The Input :

- Gamma Ray

The Output :

- Friction Angle

Theory

This method maps Gamma Ray to Friction Angle with a linear correlation. A cutoff is applied to Friction Angle. With default parameters, GR 120 gAPI is mapped to FANG 20 dega and GR 40 gAPI is mapped to FANG 35 dega. If the calculated FANG is less than 15 dega, it is forced to 15 dega. If it is greater than 40 dega, it is forced to 40 dega. You can change the default parameters.

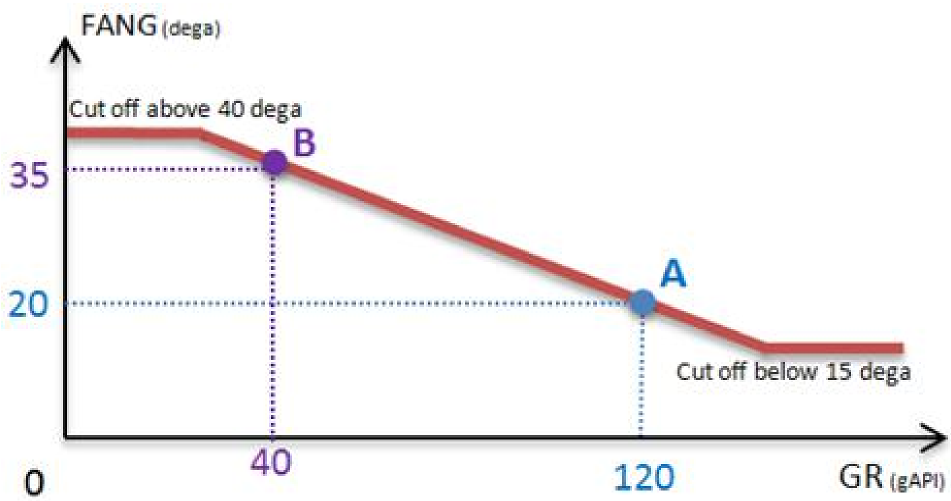

Figure (3. 2) : Friction angle from GR

3.2.3 Cohesion :

The Correlation :

- Cohesion from UCS and Friction Angle

3.2.3.1 Correlation to Compute Cohesion

The Input :

- Unconfined Compressive Strength
- Friction angle

The Output :

- Cohesion Strength

Theory :

$$COH = \frac{UCS}{2[\sqrt{1+(tanFANG)^2}+tanFANG]} \qquad \text{(Equation 3. 13)}$$

Where

COH ≡ Cohesion Strength

UCS ≡ Unconfined Compressive Strength

FANG ≡ Friction angle

3.2.4 Tensile Strength :

The Correlation :

- Function of UCS Correlation (for Tensile Strength)

3.2.4.1 Function of UCS Correlation (for Tensile Strength)

The Input :

- Unconfined Compressive Strength

The Output :

- Tensile strength

Theory :

This model provides the simple correlation to compute tensile strength directly from UCS strength :

$$TSTR = K \times UCS \qquad \text{(Equation 3. 14)}$$

Where:

K ≡ Facies and zone based factor, default: 0.1

This default value is based on the Griffith Elastic-brittle theory which gives the ratio of compressive strength versus tensile strength for 8 ~ 12 .

3.3 Horizontal Stress :

The Horizontal stress module calculates the horizontal stresses and their direction based on the assumption that the vertical stress is a principal stress , and that is done by several methods which are :

Mohr-Coulomb Stress model :

Mohr-Coulomb Stress Model is a failure model that gives a relationship between two principal stresses if the formation is at failure

Poro-Elastic Horizontal Strain Model :

Poro-Elastic Horizontal Strain Model is the most generally used method for horizontal stresses calculation.

Function of Minimum Horizontal Stress Model :

This method is to calculate the Maximum Horizontal Stress as a function of Minimum Horizontal Stress, which can be computed from poro-elastic horizontal strain model.

Maximum and Minimum Horizontal Stress Ratio Model :

The Integrated Stress Analysis (ISA) commercial software plugin provides an advanced workflow for calculating horizontal stresses and direction from acoustics measurements and determine stress regime and direction of the maximum horizontal stress from images and calipers. ISA can output calibration points of horizontal stress ratio and stress regime Q factor.

Q Factor Model :

To compare with calibrations of Q factor from ISA, stress regime Q factor is calculated in this method .

3.3.1 Mohr-Coulomb Stress model :

Mohr-Coulomb Stress Model is a failure model that gives a relationship between two principal stresses if the formation is at failure. The model assumes that the maximum in-situ shear stress is governed by the shear strength of the formation, which is characterized by the Mohr-Coulomb failure criterion. The model is not limited to any specific deformation mechanism or principal stress direction. Therefore, you can apply it to sedimentary basins subjected to either active tectonic compression or extension. Assuming that the vertical stress is a principal stress, the limits of horizontal stresses in the stress domain are the lower limit of minimum horizontal stress, and the upper limit of maximum horizontal stress. Both are obtained from the Mohr-Coulomb Stress Model.

The Input :

- Vertical Stress
- Pore Pressure
- Friction Angle

The Output :

- Minimum Horizontal Stress
- Maximum Horizontal Stress

Algorithm :

According to different tectonic plate movements, you can define three stresses regimes if the rock fails in shear. These stresses regimes are associated with the three classic fault regimes, normal, thrust and strike-slip fault regimes. For thrust fault regime: $\sigma_H > \sigma_h > \sigma_V$

In this case, the maximum principal stress is in the horizontal plane and is therefore maximum horizontal stress and the minimum principal stress is the vertical stress , From the following equation :

$$\boldsymbol{\sigma_H = tan^2(\frac{\pi}{4}+\frac{\theta}{2}) \times (\sigma_V - \alpha P_p) + \alpha P_p} \quad \text{(Equation 3. 15)}$$

You can compute maximum horizontal stress upper limit For normal fault regime:

$\sigma_V > \sigma_H > \sigma_h$

In this case, vertical stress is the first principal stress and minimum horizontal stress is the third principal stress , From the following equation:

$$\boldsymbol{\sigma_h = (\sigma_V - \alpha P_p) \div tan^2(\frac{\pi}{4} + \frac{\theta}{2}) + \alpha P_p} \quad \text{(Equation 3. 16)}$$

You can compute minimum horizontal stress lower limit can be computed .

3.3.2 Poro-Elastic Horizontal Strain Model :

Poro-Elastic Horizontal Strain Model is the most generally used method for horizontal stresses calculation , Its Assuming flat-layered poro-elasticity deformation in the formation rock, a pair of particular constant strains , ε_{SHMIN} and ε_{SHMAX} are applied to the formation in the directions of minimum and maximum stress respectively. The Poro-Elastic Horizontal Strain Model can be expressed using Static Young's modulus, Poisson ratio, Biot's constant, overburden stress, and pore pressure. You cannot directly measure ε_{SHMIN} and ε_{SHMAX} By adjusting these strains, you can calibrate the calculated stresses with the measured horizontal stresses at depth .

The Input :

- Poisson Ratio (Static)
- Vertical Stress
- Young's Modulus (Static)
- Pore Pressure

The Output :

- Minimum Horizontal Stress
- Maximum Horizontal Stress

Algorithm :

For a fluid saturated porous material that is assumed to be linear elastic and isotropic, considering anisotropic tectonic strain , the horizontal stresses σ_h and σ_H are equal to :

$$\boldsymbol{\sigma_h = \frac{v}{1-v}\sigma_v - \frac{v}{1-v}\alpha P_p + \alpha P_p + \frac{E}{1-v^2}\varepsilon_h + \frac{vE}{1-v^2}\varepsilon_H} \quad \text{(Equation 3. 17)}$$

$$\boldsymbol{\sigma_H = \frac{v}{1-v}\sigma_v - \frac{v}{1-v}\alpha P_p + \alpha P_p + \frac{E}{1-v^2}\varepsilon_H + \frac{vE}{1-v^2}\varepsilon_h} \quad \text{(Equation 3. 18)}$$

Where:

$\varepsilon_h \equiv$ minimum principal horizontal strain.

$\varepsilon_H \equiv$ maximum principal horizontal strain .

Application

- The equations honour the phenomenon that a stronger rock (with higher Young's modulus) supports higher horizontal stress in tectonic active area .
- This model can account for situations where sandstones are under higher horizontal stress than adjacent shales. The overburden stress is a principal stress but not necessarily the maximum principal one. If the strains are equal to zero, this model reduces to the uniaxial strain model .

3.3.3 Maximum and Minimum Horizontal Stress Ratio Model :

The Integrated Stress Analysis (ISA) commercial software plugin provides an advanced workflow for calculating horizontal stresses and direction from acoustics measurements and determine stress regime and direction of the maximum horizontal stress from images and calipers. ISA can output calibration points of horizontal stress ratio and stress regime Q factor .

The Input :

- Maximum Horizontal Stress

- Minimum Horizontal Stress

Theory :

To compare with calibrations of stress ratio from ISA, stress ratio is calculated in this method .

$$RATIO = \frac{\sigma_H}{\sigma_h}$$ (Equation 3. 19)

3.3.4 Q Factor Model :

To compare with calibrations of Q factor from ISA, stress regime Q factor is calculated in this method .

The Input :

- Vertical Stress

- Maximum Horizontal Stress

- Minimum Horizontal Stress

The Output :

- indicates the stress regime

Theory :

For a Normal fault stress regime ($\sigma_V > \sigma_H \geq \sigma_h$) :

$$Q = \frac{\sigma_H - \sigma_h}{\sigma_v - \sigma_h} \quad (Q >= 0 \; and \; < 1) \qquad \text{(Equation 3. 20)}$$

For a Strike-slip fault stress regime ($\sigma_H \geq \sigma_V > \sigma_h$) :

$$Q = 2 - \frac{\sigma_V - \sigma_h}{\sigma_H - \sigma_h} \quad (Q >= 1 \; and \; < 2) \qquad \text{(Equation 3. 21)}$$

For a Strike-slip fault stress regime ($\sigma_H \geq \sigma_V > \sigma_h$) :

$$Q = 2 + \frac{\sigma_h - \sigma_V}{\sigma_H - \sigma_V} \quad (Q >= 2 \; and \; < 3) \qquad \text{(Equation 3. 22)}$$

3.4 Wellbore Stability Analysis :

The Wellbore stability (Wbs) analysis computes safe drilling mud weight windows and synthetic borehole failure image based on well centric Mechanical Earth Model (MEM) and mud weight data used for drilling.

Wellbore instability occurs when the stresses near the wellbore exceed the strength of the formation. The primary inputs to this type of modeling include a description of the stresses in the earth along with a description of the formation strength. These input parameters are contained in the Mechanical Earth Model, The linear elastic theory is used to estimate the stresses near the wellbore , Positive numbers are used to describe compressive stresses and negative numbers are used to describe tensile stresses. Effective stresses are used in the computations of yield and failure.

There are two main sets of stresses in the analysis of wellbore instability:

- Far-field stresses

- Wellbore stresses

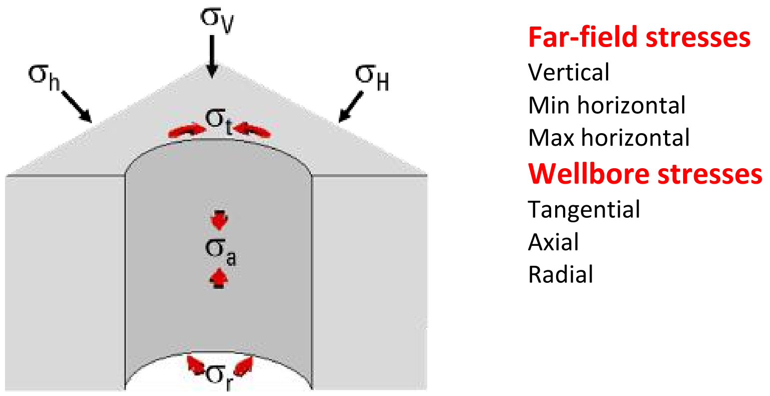

Figure (3. 3) : Far-field stresses and Wellbore stresses

The Wellbore Stability Analysis will provide the following analysis :

Shear Failure Criteria

When a formation is subjected to orthogonal compressive stresses, the grains will be sheared apart at an angle, α . This angle is measured between the direction of maximum stress, and σ_1 , and the normal to the failure plane σ_3 is the minimum stress.

Shear Failure Models

In theory, there are four shear failure modes: Wide Breakout, Shallow Knockout, Low Angle Echelon, and High Angle Echelon. To make it simple in practice, Techlog merged Low Angle Echelon into Wide Breakout and merged High Angle Echelon into Shallow Knockout.

Tensile Failure Criteria

When a formation is subject to a tensile stress, the constituent grains are pulled apart in the direction of the tensile stress. Eventually, a crack perpendicular to the tensile stress is created, and the formation fails in tension.

Reservoir Pressure Depletion

Stresses versus the reservoir pore pressure depletion including the depleted minimum horizontal stress, the depleted maximum horizontal stress and the depleted formation pore pressure.

Wellbore Stability Analysis - Depth of Damage

The breakout gradient is the calculated equivalent mud weight of initial wellbore shear failure.

Wellbore Stability Analysis with Inclined Stresses

Vertical stress is a principal stress in most cases of interest. Therefore, express the in-situ stresses through the vertical stress magnitude, minimum and maximum horizontal magnitudes, and the azimuth of one of the horizontal.

3.4.1 Shear Failure Criteria :

When a formation is subjected to orthogonal compressive stresses, the grains will be sheared apart at an angle, α . This angle is measured between the direction of maximum stress, and σ_1 , and the normal to the failure plane σ_3 is the minimum stress. The shear stress τ is defined with:

$$\tau = -\frac{1}{2}(\sigma_1 - \sigma_3)\sin 2\alpha \quad \text{(Equation 3. 23)}$$

For a small shear stress, formations might behave elastically. This means that when a material is deformed by a stress, the material returns to the original position when the stress is released. As the shear stress increases and the yield strength of the formation is exceeded, the grains begin to re-orient, and can no longer return to their original position. Two planes of weakness form in the material symmetric about the maximum stress. But because of natural variations in the strength of the formation material, the weaker of the two planes dominates the failure process. This explains the single plane of failure typically observed in wellbore images.

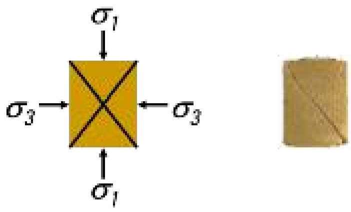

Figure (3. 4) : Compression (or Shear) Failure

3.4.1.1 Mohr-Coulomb Criterion

A common criterion of shear failure, known as Mohr-Coulomb, is given by:

$$\sigma_1 = C_o + \sigma_3 \tan^2 \gamma \qquad \text{(Equation 3. 24)}$$

It states that the formation fails when the maximum compressive stress overcomes two material properties that resist deformation. These are the unconfined compressive strength, C_o, and the angle of internal friction, f, which is related to g by the following equation:

$$\gamma = 45^o + \frac{\phi}{2} \qquad \text{(Equation 3. 25)}$$

Shear failure occurs in a plane that depends on the direction of the two stresses most different in magnitude. The orientation of that plane in relation to the borehole explains some of the different failure geometries observed in wellbore images.

3.4.1.2 Modified Lade Criterion

A failure criterion describing the shear failure mechanism of rock mass. Mohr-Coulomb model is overconservative for wellbore condition, as it ignores the effect of middle stress. The modified Lade criterion has considered the effect of intermediate principal stress. The modified Lade criterion predicts critical mud weight values that are less conservative than those predicted by the Mohr-Coulomb criterion and Mogi-Coulomb criterion. The equation of the criterion can be represented as:

$$\frac{I_1{}^3}{I_3} = 27 + \eta$$ (Equation 3. 26)

Where :

I_1 and I_3 are the first and third invariables of the stress tensor .
η is the strength parameter .

3.4.1.3 Mogi-Coulomb Criterion :

A failure criterion describing the shear failure mechanism of rock mass by using a linear relationship of shear stress and normal stress, similar to the Mohr-Coulomb model one. It is well known that Mohr-Coulomb model is over conservative for wellbore stability prediction, as it ignores the effect of the intermediate principal stress. The equation of the criterion can be represented as:

$$\tau_{oct} = a + b\sigma_{m,2}$$ (Equation 3. 27)

$$\tau_{oct} = \frac{1}{3} \times \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$ (Equation 3. 28)

$$\sigma_{m,2} = \frac{(\sigma_1 + \sigma_3)}{2}$$ (Equation 3. 29)

$$a = \frac{\sqrt{2}(1 - sin\phi)}{3} UCS$$ (Equation 3. 30)

$$b = \frac{2\sqrt{2}}{3} sin\phi$$ (Equation 3. 31)

Where:

σ_1 and σ_2 and σ_3 are three principal stresses .

3.4.2 Shear Failure Models :

In theory, there are four shear failure modes: Wide Breakout, Shallow Knockout, Low Angle Echelon, and High Angle Echelon. To make it simple in practice, Techlog merged Low Angle Echelon into Wide Breakout and merged High Angle Echelon into Shallow Knockout.

3.4.2.1 Wide breakout (Shear Failure Mode 1)

For a vertical borehole, the Wide Breakout mode occurs when:

- The tangential stress is the maximum principal stress .
- The radial stress (well pressure) is the minimum principal stress .

These two stresses act in the horizontal plane to cause shear failure, which is centered at the azimuth of the minimum horizontal stress. This failure tends to cover a large arc, from 30° to 90°.

For a deviated borehole, this software identifies this kind of shear failure when the maximum principal stress is near the tangential direction in a plane perpendicular to the borehole axis (when the angle between the stress direction and the borehole axis is larger than 45°).

3.4.2.2 Shallow knockout

For a vertical borehole, the Shallow knockout mode occurs when:

- The axial stress is the maximum stress
- The radial stress is the maximum stress

These two stresses act in the vertical plane to cause the failure, which is aligned with the minimum horizontal stress direction. The circumferential coverage is small and this mode could easily be confused with a vertical fracture. A schematic drawing is shown in the figure above.

For a deviated borehole, this software assumes that the shear failure mode is also a Shallow Knockout when the angle between the maximum principal stress direction and the borehole axis is less than or equal to 45°.

3.4.2.3 Low angle echelon (merged into Wide breakout)

The low angle echelon shear failure mode occurs when:

- The tangential stress is the maximum principal stress.
- The vertical stress is the minimum principle stress so that a low-angle shear fracture is made.

3.4.2.4 High angle echelon (merged into Shallow knockout)

The High Angle Echelon shear failure ode occurs when:

- The tangential stress (well pressure) is the minimum principal stress
- The vertical stress is the maximum principal stress so that shear failure will make high-angle fractures that cover up to a quarter of the borehole circumference .

3.4.3 Tensile Failure Criteria :

When a formation is subject to a tensile stress, the constituent grains are pulled apart in the direction of the tensile , Commercial software uses the following criterion which predicts tensile failure as soon as the minimum effective principle stress reaches the tensile strength of rock :

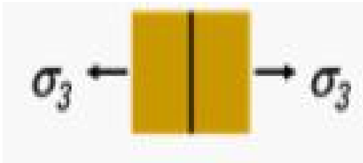

Figure (3. 5) : Tensile Failure

$$\sigma_3 = -T_o$$ (Equation 3. 32)

The single material property working against the tensile stress is the tensile strength of the formation, T_0.

Where:

$\sigma_3 \equiv$ minimum effective principal stress.

$T_o \equiv$ rock tensile strength.

3.4.4 Reservoir Pressure Depletion :

Stresses versus the reservoir pore pressure depletion including the depleted minimum horizontal stress, the depleted maximum horizontal stress and the depleted formation pore pressure.

For homogeneous isotropic formation, with the assumption of uniaxial strain condition, the relationship between the minimum horizontal stress and the overburden stress is :

$$\sigma_h - \alpha \times P_p = \frac{v}{1-v}(\sigma_v - \alpha \times P_p)$$ (Equation 3. 33)

Where :

$\alpha \equiv$ Biot's elastic constant

$v \equiv$ Poisson's ratio

$\sigma_h \equiv$ horizontal stress

$\sigma_v \equiv$ vertical stress

$P_p \equiv$ pore pressure

Evaluate the horizontal stresses as follows when the reservoir is depleting :

$$\sigma_H{}^d = \sigma_H - Kappa \times P_p \times Depletion$$ (Equation 3. 34)

$$\sigma_h{}^d = \sigma_h - Kappa \times P_p \times Depletion$$ (Equation 3. 35)

Where:

$\sigma_H{}^d \equiv$ depletion maximum horizontal stress

$\sigma_h{}^d \equiv$ depletion minimum horizontal stress

Depletion $\equiv$ pore pressure depletion percentage

Kappa ≡ factor indicating how depletion affects horizontal stresses, which you can estimate as :

$$\boldsymbol{Kappa} = (\mathbf{1} - \frac{\boldsymbol{\nu}}{\mathbf{1}-\boldsymbol{\nu}}) \times \boldsymbol{\alpha}$$ (Equation 3. 36)

The depleted pore pressure is :

$$\boldsymbol{P_p}^{\boldsymbol{d}} = (\mathbf{1} - \boldsymbol{Depletion}) \times \boldsymbol{P_p}$$ (Equation 3. 37)

3.4.5 Estimate Pore Pressure :

Estimating pore pressure (PP) and fracture gradients (FG) in a wellbore defines the hydraulic safe mud weight window required to drill a well.

Overburden stress is determined from measured or estimated bulk density data. Effective vertical stress is estimated from log measurements or seismic data using pore pressure methods. For the shale zone, the pore pressure is obtained from the difference of the overburden stress and effective stress. In permeable zones, you can estimate PP using linear interpolation between the shale points above and below this zone, or using constant gradient, or using a user-input curve. A post-process is conducted to combine the results from different methods by zones, if needed .

- Vertical Stress and Terzaghi's Law
- Fracture Gradient

3.4.5.1 Vertical Stress and Terzaghi's Law

The vertical effective stress is defined using Terzaghi's law :

$$\boldsymbol{\sigma'_V} = \boldsymbol{\sigma_V} - \boldsymbol{P_p}$$ (Equation 3. 38)

Then, Terzaghi's law is generalized to account for matrix and fluid compressibility, and the vertical effective stress is :

$$\boldsymbol{\sigma'_V} = \boldsymbol{\sigma_V} - \boldsymbol{\alpha P_p}$$ (Equation 3. 39)

Where α is the Biot coefficient and is usually close to 1.0 for the shale stone.

Once the vertical stress is calculated from density or regional compaction trends, and the vertical effective stress is computed from data such as sonic slowness, seismic velocity, resistivity, drilling exponent, you can estimate the pore pressure by the difference of vertical stress and effective vertical stress.

3.4.5.2 Normal Pore Pressure :

As sediment is buried, the increasing weight of the overburden squashes the sediment causing the grains to compact, squeezing out water between the grains and reducing the porosity .

Normal pressure refers to the pore pressure of formations in which the pore pressure follows a hydrostatic gradient. When a formation is over-pressured, its pore pressure gradient can be as high as the overburden gradient. The normal Pore Pressure is often calculated using a linear method:

$$\boldsymbol{PP_{normal} = PP_o + k \times z} \qquad \text{(Equation 3. 40)}$$

Where:

Z ≡ TVD .
PP_o ≡ Pressure at sea floor.
K ≡ Constant gradient (psi/ft).

3.4.5.3 Pore Pressure Calculation (Eaton Method):

Eaton method is one the most widely used pore pressure estimation method in the industry and is based on Eaton's work in the Gulf of Mexico. Eaton method uses a semi-logarithmic normal trend line. The various log measurements (R) used by the Eaton Method are resistivity, sonic or seismic interval velocity. You can calculate pore pressure as follows:

$$\boldsymbol{P_p = \sigma_V - (\sigma_V - P_{pnorm}) \times \alpha \times \left(\frac{R}{R_{norm}}\right)^n} \qquad \text{(Equation 3. 41)}$$

In linear trendlines:

$$\boldsymbol{R_{norm} = R_o + kz} \qquad \text{(Equation 3. 42)}$$

In semi-log trendlines :

$$\boldsymbol{Log\ (R_{norm}) = R_o + kz} \qquad \text{(Equation 3. 43)}$$

Where:

Z ≡ Depth measured from the sea floor.

R ≡ Measurement value.

R_o ≡ Measurement of sediments at the sea floor.

R_{norm} ≡ Measurement value if the formation was normally pressured (it means the normal trend line).

P_{norm} ≡ Normal pore pressure.

α and n are fitting parameters named Eaton factor and Eaton exponent respectively.

The default values for Eaton method using compressional slowness are:

$\alpha = 1$ and $n = 3$

The default values for Eaton method using Resistivity are:

$\alpha = 1$ and $n = 1.2$

The default values for Eaton method using D-Exponent are:

$\alpha = 1$ and $n = 1.2$

3.4.5.4 Pore Fluid Pressure in Non-shale Formations :

In permeable formations, it is generally assumed that fluid can move freely in the different layers and that there is a continuous path for the fluid to go between any depth in the selected zone and the reference point. PP cannot be estimated from logs as in shale zones. Pore pressure changes linearly with depth:

$$\boldsymbol{PP = PP_{ref} + \rho_f \times g \times (TVD - TVD_{ref})} \quad \text{(Equation 3. 44)}$$

Where:

PP_{ref} ≡ Reference pore pressure.

TVD_{ref} ≡ Reference depth.

ρ_f ≡ Fluid density.

g ≡ Accelerator due to gravity.

The above equation is implemented in Non-shale zone > Constant gradient method. In a pore pressure prediction workflow, where pore pressure estimates are made in the shale zones above and below the non-shale layer, you can choose the TVD ref to be either:

- Depth just above the non-shale layer (from shale above option)
- Depth just below the non-shale layer (from shale below option)

The middle of the non-shale layer using the average between the pore pressure above and below the non-shale layer (the option of Average between shales) Alternatively, you can also set permeable zones to absent value or to the values from a user-input curve. You can also use a linear interpolation between the depths above and below the non-shale formations to fill the gaps quickly .

3.4.6 Fracture Gradient Calculation

Fracture gradient (FG) is calculated from pore pressure (PP) and overburden gradient (σ_V).

The following formula is used:

$$FG = K \times (\sigma_V - \alpha P_p) + \alpha P_p \quad \text{(Equation 3. 45)}$$

Where:

α ≡ Biot coefficient.

K ≡ Stress ratio (unitless), which is the horizontal effective matrix stress over the effective vertical stress.

All the fracture gradient methods are only different in the method of computation of K .

4.4.6.1 Eaton methods (Eaton, Gulf coast)

An effective Poisson's ratio in shale (υ) is introduced in the Eaton method by the following equation:

$$K = \frac{\upsilon}{1-\upsilon} \quad \text{(Equation 3. 46)}$$

If you use this approach, the above equation cannot be applied too literally. Since sediments deform plastically when they are compacted, the amount of horizontal compression generated during the burial is greater than elasticity theory would predict. Consequently, using "true" elastic Poisson's ratios in the above equation can cause Eaton method to significantly underestimate fracture gradients.

In the absence of a leak-off test data, Eaton & Eaton (1997) published two analytical relations for an effective Poisson's ratio in shale (υ) as a function of depth below mud line.

4.4.6.2 Eaton - Gulf Coast

The K is calculated from effective Poisson's ratio (υ) which is computed with the following correlation:

Above 4,999.9 ft

$$\nu = -7.5 \times 10^{-9} \times TVD_{Ref.GL}{}^2 + 8.0214286 \times 10^{-5} \times TVD_{Ref.GL} + 0.2007142857 \quad \text{(Equation 3. 47)}$$

Below 5,000 ft

$$\nu = 1.77258 \times 10^{-10} \times TVD_{Ref.GL}{}^2 + 9.4748424 \times 10^{-6} \times TVD_{Ref.GL} + 0.3724340861 \quad \text{(Equation 3. 48)}$$

3.5 Lost Preventive Materials module :

Lost Preventive material (LPM) are designed to seal and effectively increase fracture resistance allowing the operator to drill through a weak formation zone successfully with minimal to zero losses . From the geo-mechanical model that we are done we can estimate the trouble formation and its location that may cause some problem and work to treatment it before the damage occur , that well done by Provide a model for LPM application procedure :

- Model to define criteria for wellbore strengthening (LPM selection)
- Minimum volumetric concentration requirements
- Quantitative requirements for cake thickness and to build that LPM module

we should know the following :

The pressure depletion directly affects the fracture gradient, and decreases the fracture resistance of the formation. Predictive methods are required to extrapolate the new fracture gradient in the depleted zone based on previous measured pressure data. The change in the fracture gradient can be found from the following relationship:

$$\nabla P_{fg} = a \times \nabla P_p \quad \text{(Equation 3. 49)}$$

where a is given by

$$a = 1 - \frac{\upsilon}{1-\upsilon} \quad \text{(Equation 3. 50)}$$

Where

$\nabla P_{fg} \equiv$ Change in fracture gradient

$\nabla P_p \equiv$ Change in reservoir pressure and υ is the Poisson's ratio

In developing the above ideas, the approach we have taken is to actually allow small fractures to form in the wellbore wall, and to hold them open using bridging particles near the fracture opening. The bridge must have a low permeability that can provide pressure isolation. Provided the induced fracture is bridged at or close to the wellbore wall this method creates an increased hoop stress around the wellbore. It is done by adding appropriate materials to the mud system, to produce a designer mud .

For stability Pt - Pp < Pm

P_m = Mud Pressure

P_t = Pressure at fracture tip

P_p = Pore Pressure

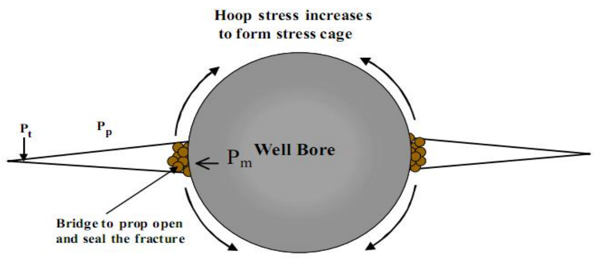

Figure (3. 6) : Bridge to prop open and scal the fracture

In permeable formations , the fluid trapped behind the bridge can dissipate pressure into the rock matrix.

3.5.1 Application of The Model: Model Input

The data that we well input to the LPM model is some of the data that calculated from the Geo-mechanical model that we build " OUTPUT DATA " to insert it in the equations that we well used to calculate the FRACTURE WIDTH DETERMINATION FOR WELLBORE STRENGTHENING & PARTICLE SIZE DISTRIBUTION OPTIMISATION MODEL to obtain the accurate formation strength and increase the strength of the week formation , and that input data is classified into :

- **Well parameters**
  - Pore pressure
  - Depleted interval depth
  - Wellbore pressure
  - Hole diameter & Fracture Length
- **Rock parameters**
  - Poisson's Ratio
  - Young's Modulus
  - Minimum & maximum horizontal stress .

3.5.2 Application of The Model : Model Output

The modelling software and materials can be applied in support of wellbore pressure containment and techniques to more accurately predict and optimize LPM selection, fracture width, target particle size distribution and concentration. Based on estimated fracture widths, hole diameter, the range of particle size, the model can utilize the proper types and sizes of materials to plug the pores and/or an initiated fracture. For pore bridging in the reservoir these materials are selected from a full range of ground marble products with d50's ranging from 5 to 150 microns. For borehole stress treatments, these materials generally are selected from a full range of specialized resilient graphitic carbon and ground marble products, with d50's ranging between 5 and 1200 microns .

3.5.2.1 Fracture Width Determination For Wellbore Strengthening

This section addresses fracture size/width for any vertical, deviation and orientation under anisotropic stress conditions can be predicted. The closed form solution for the fracture aperture is based on linear fracture mechanics. It also depends on well deviation and orientation, fracture length (L), wellbore radius or diameter (R), in-situ stresses (Sv, SH and Sh), bottom hole pressure and rock elastic properties (Young modulus and Poisson's ratio). The model assumes that when L is much larger than the radius (R) of the wellbore.

$$\boldsymbol{W(x) = \frac{4\times(1-v^2)}{E} \times (P_w - S_{min}) \times \sqrt{(L+R)^2 - X^2}}$$ (Equation 3. 51)

Where L is assumed to be 6" in the Niger Delta and other part of the world. To optimise the calculated fracture width W(x), evaluation must be done at the top TVD target TVD and bottom TVD for minimum, most likely and maximum W(x) for ± 25m interval. Once the expected fractured width is calculated, the amount, particle size distribution (PSD), the type and concentration of the LPM can be determined. In other to model the concentration of LPM to effect wellbore strengthening, the particle size distribution optimisation method is developed.

3.5.2.1 Partical Size Distribution Optimization Model

It is desirable to select a particle size distribution that will efficiently and quickly bridge the largest, medium and smaller pore size fractions because particle size appeared to be the most important variable for obtaining a fracture sealing response. These optimum PSD's are selected based on the D90, D50 and D10 of the reservoir pore throat distribution. Where D90 is the percent by volume of particles have size less than or equal to that value, similarly D10, D50 and D90 . For optimize particle size distribution, we assume that d10 = 0.0w, d50 = 0.4w and d90 = 1.0w for PSD design strategy. Monte Carlo simulator is used to calculate PSD and generate a probability distribution for the maximum fracture width and particulate formulation using expected uncertainties in rock properties and drilling parameters. The Target Cumulative distribution (Log-normal cumulative probability function) :

$$\boldsymbol{F(d) = \frac{1}{2}\left\{1 + erf\left[\frac{ln(d)-\mu}{\sqrt{2\sigma^2}}\right]\right\}}$$ (Equation 3. 52)

Standard deviation :

$$\boldsymbol{\sigma^2 = 0.5 \times \left[\frac{ln(d90)-ln(d50)}{0.906194}\right]^2}$$ (Equation 3. 53)

Value :

$$\boldsymbol{\mu = ln\,(d90)}$$ (Equation 3. 54)

Cumulative distribution of the mix: least square optimisation method:

$$f(d) = w_1 g_1(d) + w_2 g_2(d) + \dots. + w_n g_n$$ (Equation 3. 55)

Objective function to minimize :

$$x^2 = \sum_{i=1}^{m} [f(d_i) - F(d_i)]^2$$ (Equation 3. 56)

Concentration of LPM :

$$LPMcon = \int \frac{PSD}{F(d)}$$ (Equation 3. 57)

Chapter 4

Result and Discussion

4. Result and Discussion

This result of case study is based on SW well data that taken from the wells to use it for calculating the required properties for provide an earth Geomechanical Model By using Commercial software to study the formation instability and provide the required data that used to create a LPM Design for protect the weak zone and prevent it from the damage that could happened to it when used improper mud weight .

4.1 Earth Geomechanical Model :

From data that obtained from SW well which is key parameters that obtained from previous expertises on the well, which used as input data for the wellbore instability analysis that can be done by using Commercial software that help to calculate Elastic properties, Rock strength, horizontal stress.

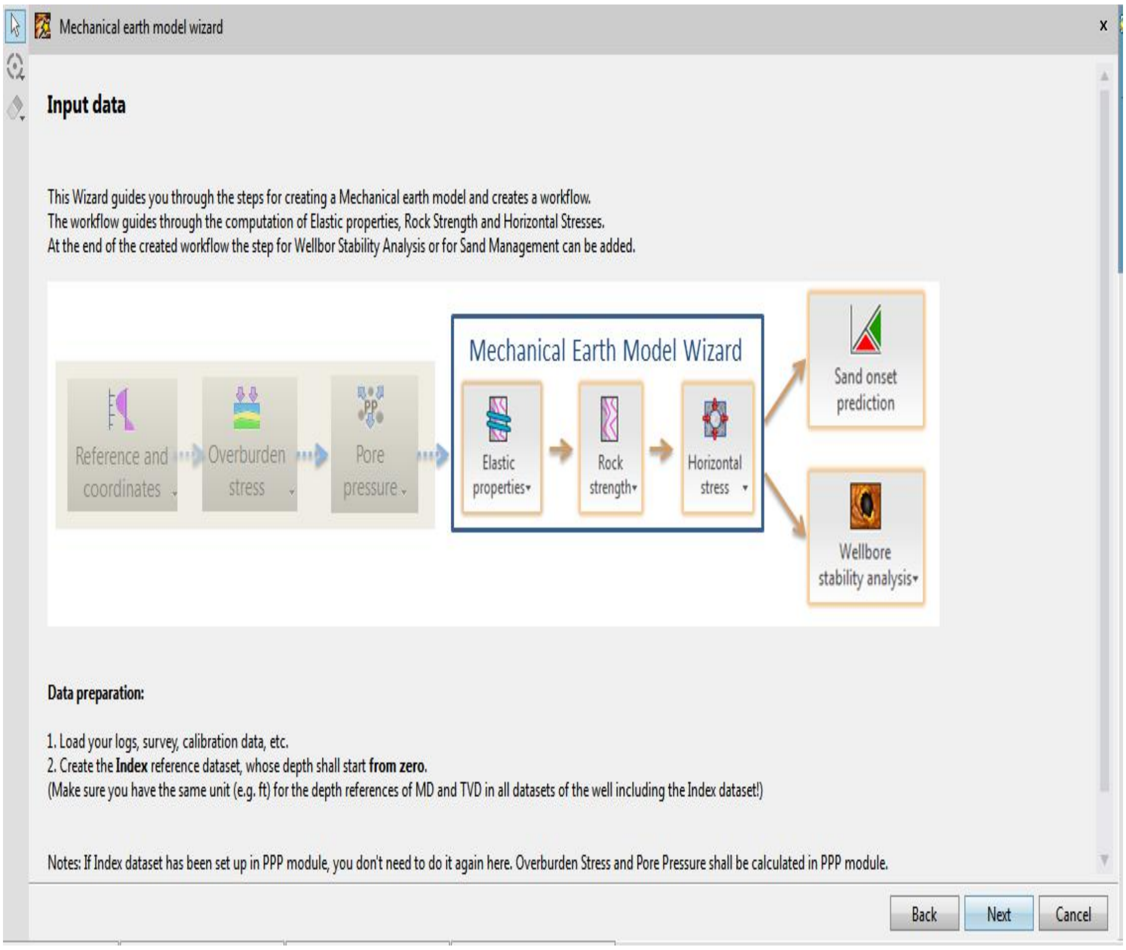

Figure (4. 1) : Mechanical Earth Model wizard

According to SW well data that applied in equations that used to create Earth Geomechanical Model , this model calculates the (Elastic properties, Rock strength, horizontal stress) that gives indication to severity of (Breakdown,shear failure,kick).
And also show the optimum mud weight that must be use without any risk of (Breakdown, shear failure, kick) .

The result taken from many zones :

AM SS Zone :

which is from (800 - 1062m)

BA SS Zone :

which is from (1063- 1691m)

GH Zone :

which is from (1692- 1931m)

ZA Zone :

which is from (1932- 2752m)

AR Zone :

which is from (2753- 2790m)

BE Zone :

which is from (2790- 3177m)

4.1.1 Geomechanical description of AM SS Formation :

The geomechanical description include of knowing the range of the optimum mud weight and the range of (kick , losses, breakdown, shear failure) and cause of it and all the risk related with it if use incorrect mud weight and show the save range for the mud weight to be used , also the nature of the zone (sand or shale) , and analysis the stresses with show the GR and ND readings .

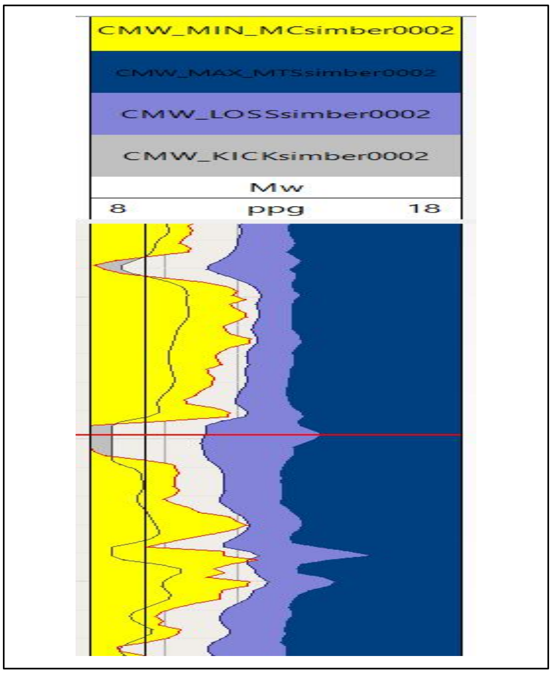

Figure (4.2): Range of optimum mud weight for (AM SS)

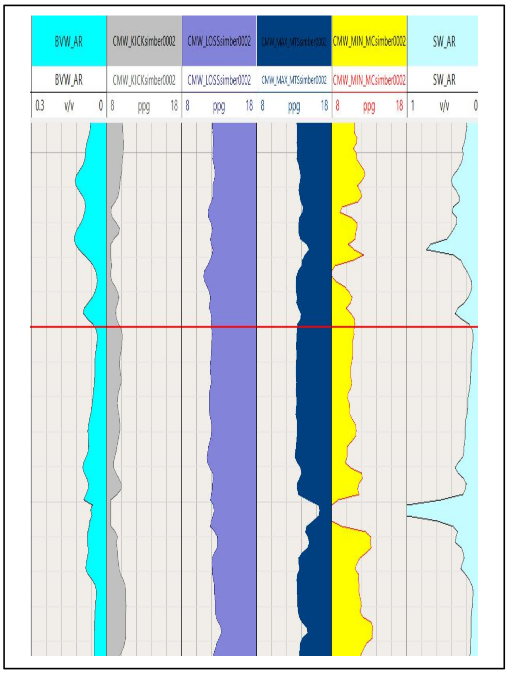

Figure (4.3) :The range of (kick , losses ,Breakdown, shear failure, water saturation) for (AM SS)

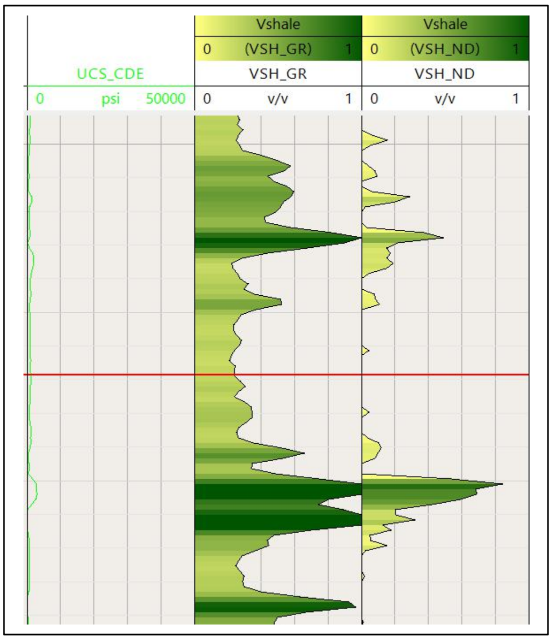

Figure (4.4): Shale Volume (VSH) from (GR ,ND) in (AM SS)

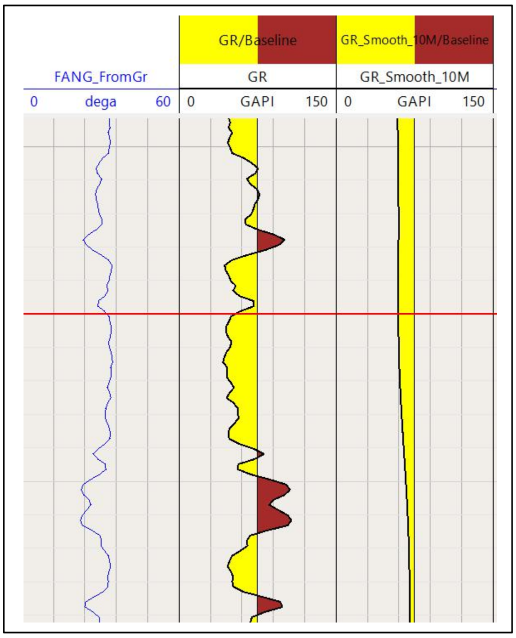

Figure (4.5): the range of sand and shale for (AM SS)

The description of the graphs in AM SS formation which is from the depth 1029 and discuse all of the formation in general :

Figure (4.2) : show that there was a high risk of fluid loss and breakdown when drilling with Mw > 11.87ppg , as well as shear failure when drilling with Mw < 10.81ppg , and the mud weight that used (Mw = 9.5 ppg) which it is located at the range of shear failure risk , so the recommended mud weight should be between (10.82 - 11.86) ppg .

Figure (4.3) : show that the range of risks individual , when the kick < 10.29 ppg , shear failure < 10.81 , losses > 11.87 , Breakdown > 13.41 , the water saturation and formation fluid volume are relatively low so that mean there are low support for the formation that lead to minimum risk of shear failure as well as high risk of loss according to the low support for the formation (low formation pressure) .

Figure (4.4) : show the shale volume from both (gamma ray log ,neutron density log), and both logs show a small concentration of shale against (sandy shale) sand that reduce the risk of collapse and stuck but that make the zone week , and well exposure to the risk of losses and breakdown .

Figure (4.5) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of sand in this zone (sandy shale).

From the Geomechanical earth model : show that AM formation is conceder as a sand formation with some layers of shale (sandy shale) which has been confirmed by (GR , ND) logs ,which indicate to low shale volume . The model also show high risk of shear failure form (800-959)m , with intermediate risk of fluid losses ,after 960 m the risk of losses become more larger, for that the formation need LPM Design to provide the ability to drill with a high mud weight without breaking the formation .

4.1.2 Geomechanical Description of (BA SS) Formation :

The geomechanical description for the zones in BA SS formation and it analysis will be discuses :

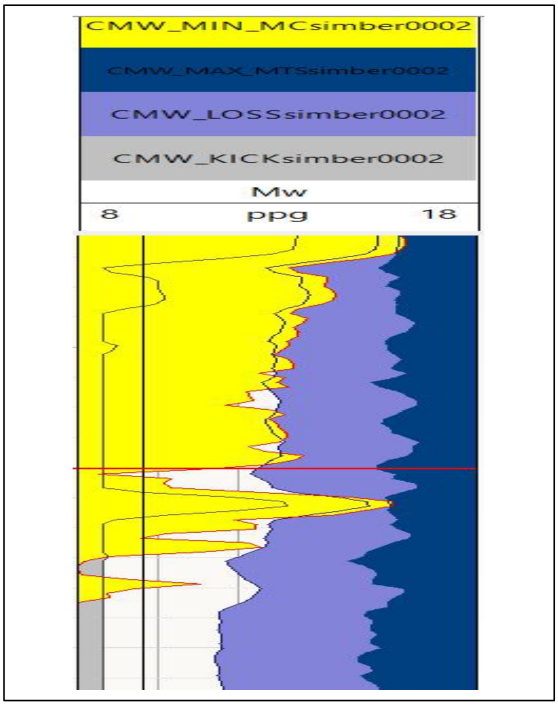

Figure (4.6) : Range of optimum mud weight for (BA SS)

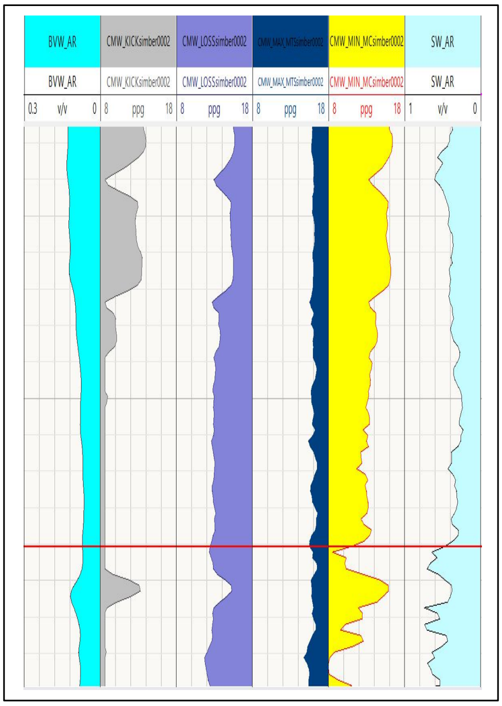

Figure (4.7) :The range of (kick , losses ,Breakdown, shear failure, water saturation) for (BA SS)

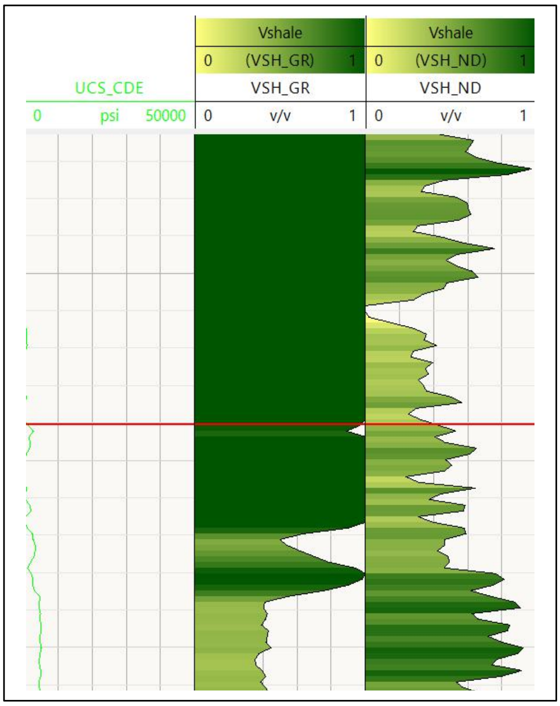

Figure (4.8) :Shale Volume (VSH) from (GR ,ND) in (BA SS)

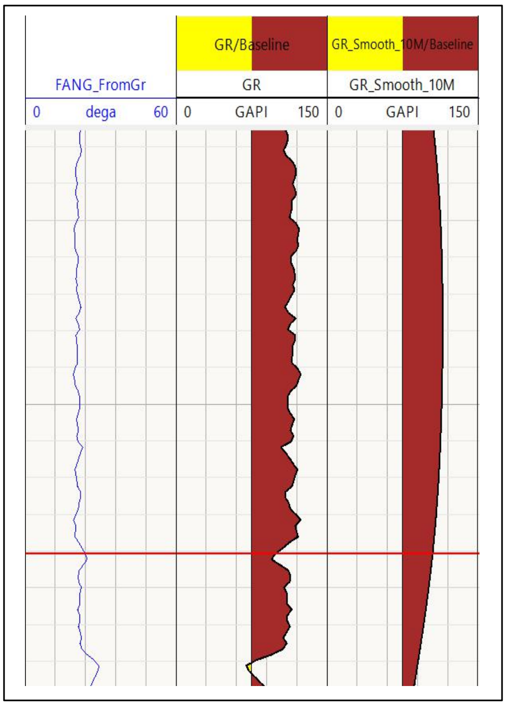

Figure (4.9) : the range of sand and shale for (BA SS)

The description of the graphs in BARAKA SS zone which is from the depth for discuss is 1379 m :

Figure (4.6) : show that there was a high risk of fluid loss and breakdown when drilling with Mw > 12.35ppg , as well as shear failure when drilling with Mw < 16.14 ppg , and the mud weight that used (Mw = 9.6 ppg) which it is located at the range of shear failure risk , so the recommended mud weight above (1379m) should be above (16.14) ppg , and below (1379m) should be between (8.5 - 12.35) ppg , so to do that we should use LPM design above 1379 m to allow us to drillling with high mud weight without fracturing the formation and then use a low mud for below (1379 m) because there is less damage than the above .

Figure (4.7) : show that the range of risks individual , when the kick < 8.5 ppg , shear failure < 16.14 ppg , losses > 12.35 ppg , Breakdown > 15.37 ppg , the water saturation and formation fluid volume are relatively high so that mean there are high support for the formation that lead to high risk of shear failure as well as relatevly low risk of loss according to using the LPM Design .

Figure (4.8) : show the shale volume from both (gamma ray log ,neutron density log), and both logs show a very large quantity of shale that increase the risk of collapse and stuck , and well exposure to the risk of shear failure .

Figure (4.9) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of shale in this zone .

From the Geomechanical earth model : show that BA formation is conceder as a sand formation with some layers of shale (sandy shale) which has been confirmed by both (GR , ND) logs , which indicate to low shale volume .The model also show high risk of fluid losses form (1062-1691) m , and form (1364 - 1381) m the risk of kick and shear failure become more larger , for that the formation need LPM Design at the upper part of the formation to provide the ability to drill with a high mud weight for the lower part without Breaking the upper part of the formation .

4.1.3 Geomechanical Description of (GH) Formation :

The geomechanical description for the zones in GH formation and it analysis will be discuses :

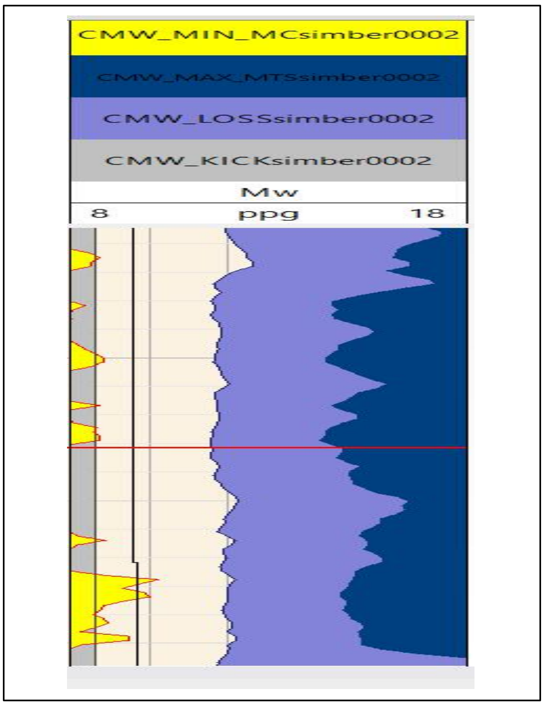

Figure (4.10): Range of optimum mud weight for (GH)

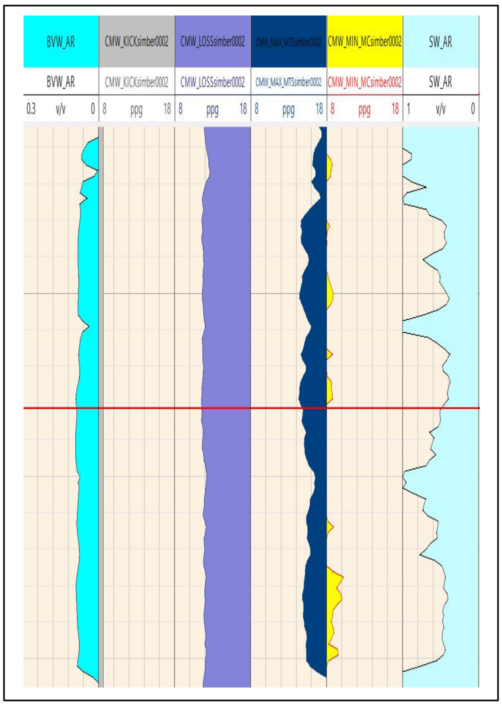

Figure (4.11) :The range of (kick , losses Breakdown, shear failure, water saturation) for (GH)

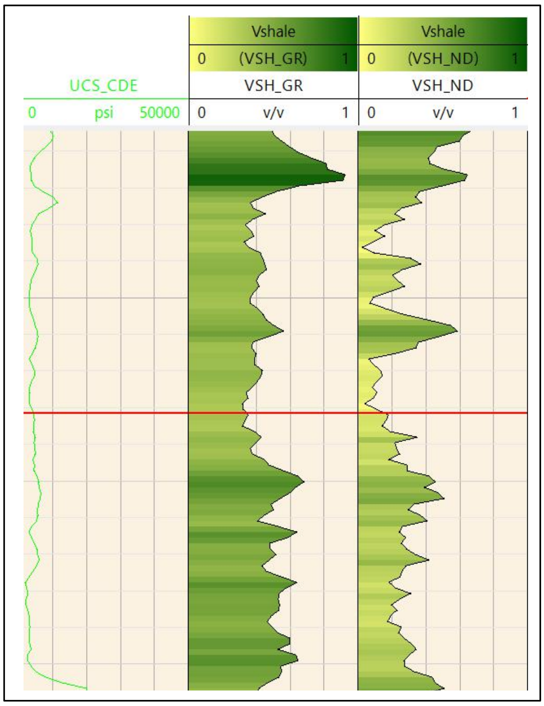

Figure (4.12) : Shale Volume (VSH) from (GR ,ND) in (GH)

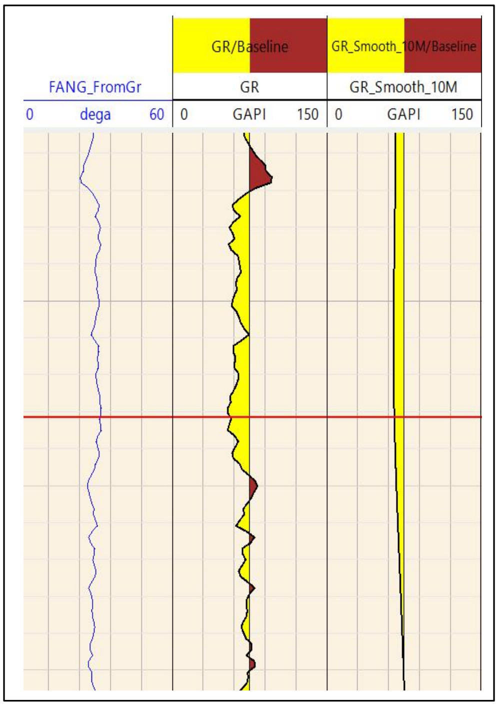

Figure (4.13) : the range of sand and shale for (GH)

The description of the graphs in GAZALA zone which is from the depth for discuss is 1810m :

Figure (4.10) : show that there was a risk of fluid loss and breakdown when drilling with Mw > 11.53 ppg , as well as shear failure when drilling with Mw < 9.3 ppg , and the mud weight that used (Mw = 9.7 ppg) which it is located at the acceptable range , so the recommended mud weight should be between (9.3 - 11.53) ppg and the 9.7 ppg is acceptable .

Figure (4.11) : show that the range of risks individual , when the kick < 8.5 ppg , shear failure < 9.3 , losses > 11.53 , Breakdown > 14.37 , the water saturation and formation fluid volume are relatively low so that mean there are low support for the formation that lead to minimum risk of shear failure as well as high risk of loss according to the low support for the formation (low formation pressure) , but the low risk of shear failure make a good availability to select the good mud weight .

Figure (4.12) : show the shale volume from both (gamma ray log ,neutron density log), and both logs show a small concentration of shale against sand , that reduce the risk of collapse and stuck and with the good concentration of water which support and make the formation not week .

Figure (4.13) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of sand in this zone (sandy shale) .

From the Geomechanical earth model : show that GH formation is conceder as a sand formation with some thin layers of shale do not exceeds the normal limit (sand formation) which has been confirmed by (GR , ND) logs , which indicate to low shale volume .The model also show high risk of fluid losses , with low risk of shear failure (collapse) , for that the formation need LPM design to provide the ability to drill with a high mud weight without get the formation breakdown .

4.1.4 Geomechanical Description of (ZA) Formation :

The geomechanical description for the zones in ZA formation and it analysis will be discuses :

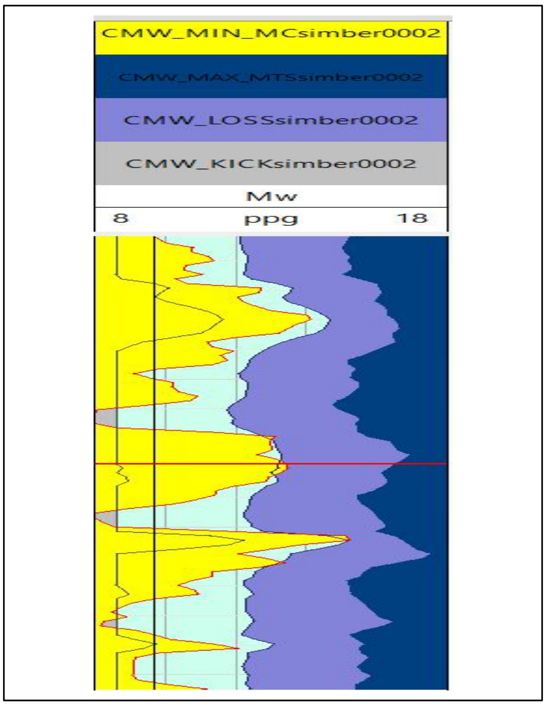

Figure (4.14) : Range of optimum mud weight for (ZA)

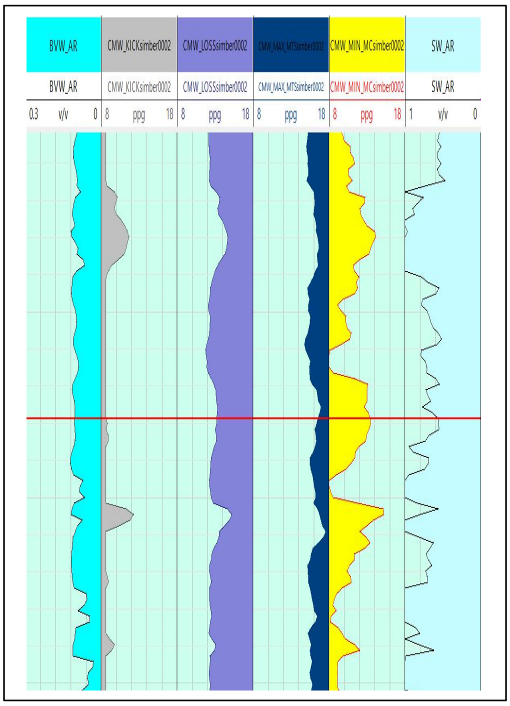

Figure (4.15) : The range of (kick , losses ,Breakdown, shear failure, water saturation) for (ZA)

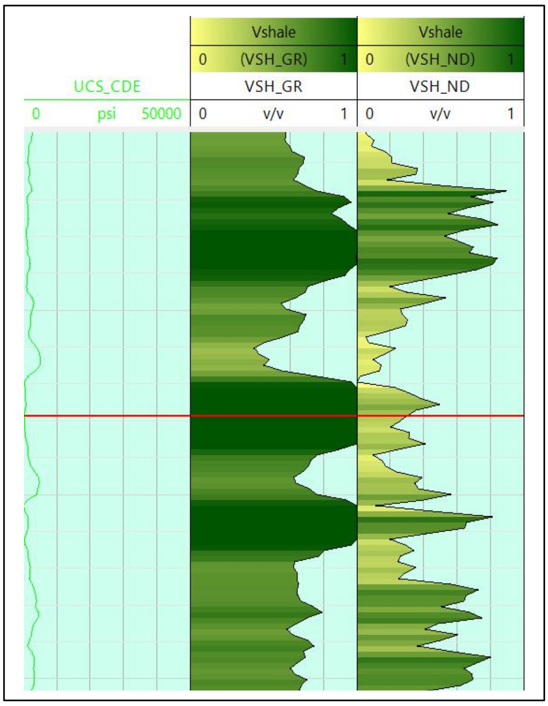

Figure (4.16) : Shale Volume (VSH) from (GR ,ND) in (ZA)

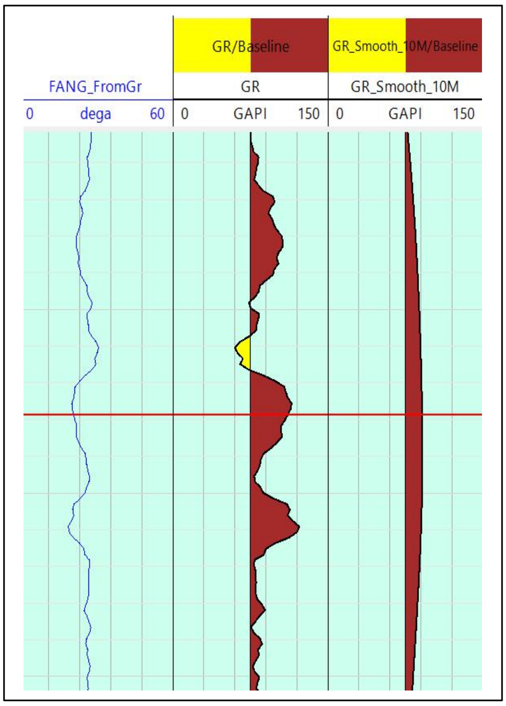

Figure (4.17) : The range of sand and shale for (ZA)

The description of the graphs in ZARGA zone which is from the depth for discuss is 2032 m :

Figure (4.14) : show that there was a high risk of fluid loss and breakdown when drilling with Mw > 12.9 ppg , as well as shear failure when drilling with Mw < 11.78ppg , and the mud weight that used (Mw = 9.67 ppg) which it is located at the range of shear failure risk , so the recommended mud weight should be between (11.78 - 12.9) ppg ,so to do that we should use LPM design at along all zone to allow us to drill with high mud weight without fracturing the formation .

Figure (4.15) : show that the range of risks individual , when the kick < 8.64ppg , shear failure < 11.78 , losses > 12.9 , Breakdown > 13ppg , the water saturation and formation fluid volume are relatively very high so that mean there are high support for the formation that lead to maximum risk of shear failure (high formation pressure) , as well as relative risk of loss according to the high mud weight that used.

Figure (4.16) : show the shale volume from both (gamma ray log , neutron density log), and both logs show relatively high concentration of shale , that increase the risk of collapse and stuck but .

Figure (4.17) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of shale in this zone with low sand percentage (shaley sand) .

From the Geomechanical earth model : show that ZA formation is conceder as a shale formation with some thin layers of sand (shaley sand formation) which has been confirmed by (GR , ND) logs , that indicate to high shale volume .The model also show high risk of fluid losses form (1932 - 2218)m , with low risk of shear failure, and above 2218m the risk of Shear failure Increase and become more dangerous than fluid loss, according to that the formation need LPM program because we need to drill with high mud weight to forced the shear failure and there is some layer have risk of losses, LPM should be directed to it, to provide the ability to drill with a high mud weight to prevent the shear failure risk without breaking the formation .

4.1.5 Geomechanical Description of (AR) Formation :

The geomechanical description for the zones in AR formation and it analysis will be discuses :

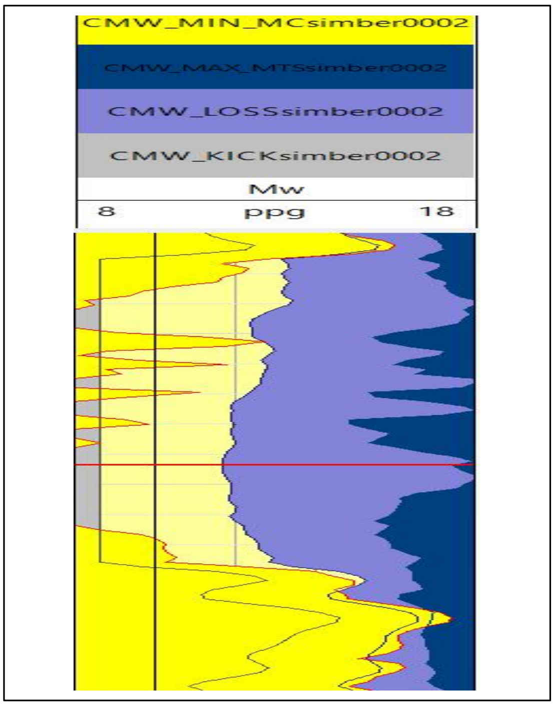

Figure (4.18):The range of optimum mud weight for (AR)

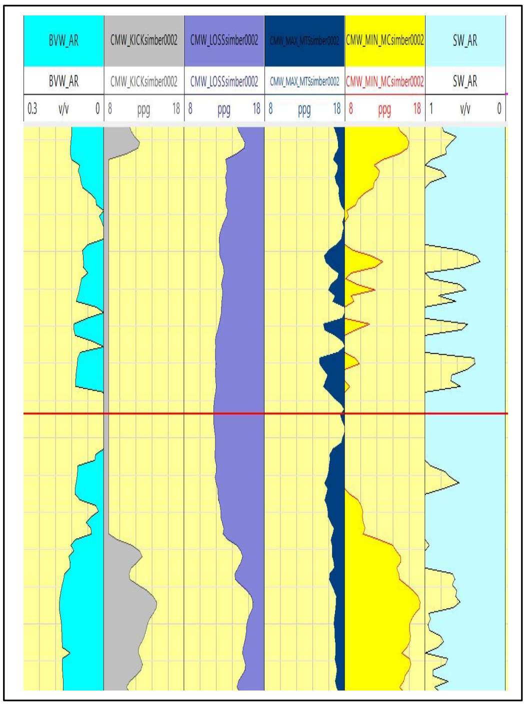

Figure (4.19) : The range of (kick , losses,Breakdown, shear failure, water saturation) for (AR)

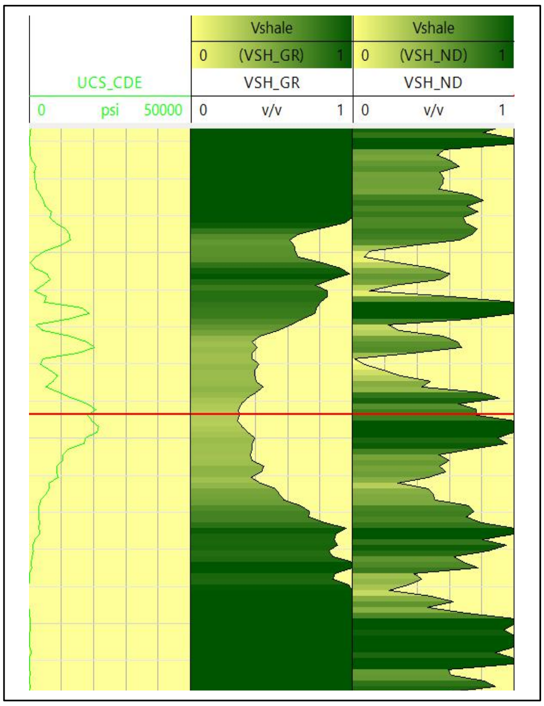

Figure (4.20) : Shale Volume (VSH) from (GR ,ND) in (AR)

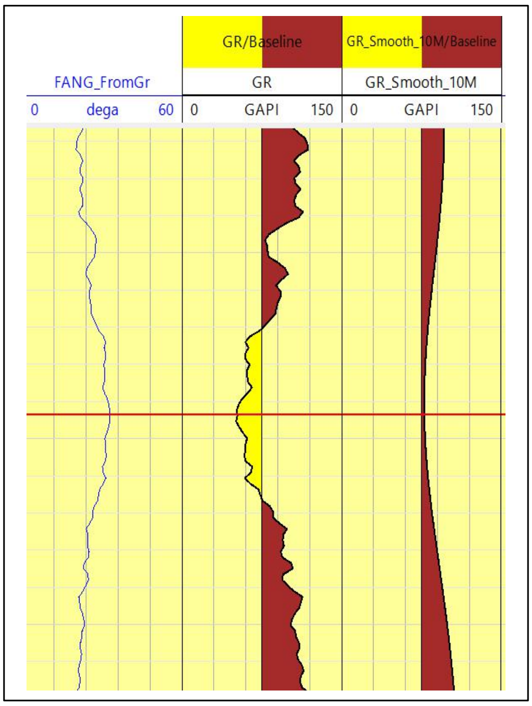

Figure (4.21) : the range of sand and shale for (AR)

The description of the graphs in ARADIBA zone which is from the depth for discuss is 2764 m :

Figure (4.18) : show that there was a high risk of fluid loss and breakdown when drilling with Mw > 11.87ppg , as well as shear failure when drilling with Mw < 10.90 ppg , and the mud weight that used (Mw = 9.8 ppg) which it is located at the range of shear failure risk , so the recommended mud weight should be between (10.90 - 11.86) ppg .

Figure (4.19) : show that the range of risks individual , when the kick < 9.2 ppg , shear failure < 10.90 , losses > 11.87 , Breakdown > 13.41 , the water saturation and formation fluid volume are relatively low so that mean there are low support for the formation that lead to minimum risk of shear failure as well as high risk of loss according to the low support for the formation (low formation pressure) .

Figure (4.20) : show the shale volume from both (gamma ray log ,neutron density log), and both logs show a high concentration of shale against (sandy shale) sand that reduce the risk of collapse and stuck but that make the zone week , and well exposure to the risk of losses and breakdown .

Figure (4.21) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of shale in this zone (shaley sand) .

From the Geomechanical earth model : show that AR formation is conceder as a shale formation with some thin layers of sand do not exceeds the normal limit (shale formation) which has been confirmed by (GR , ND) logs ,which indicate to high shale volume . The model also show high risk of shear failure, with low risk of fluid losses. LPM Design needed in some thin layer that have risk of losses , to prevent the weak layer from damage (formation breakdown) when drill with a high mud weight .

4.1.6 Geomechanical Description of (BE) Formation :

The geomechanical description for the zones in BE formation and it analysis will be discuses :

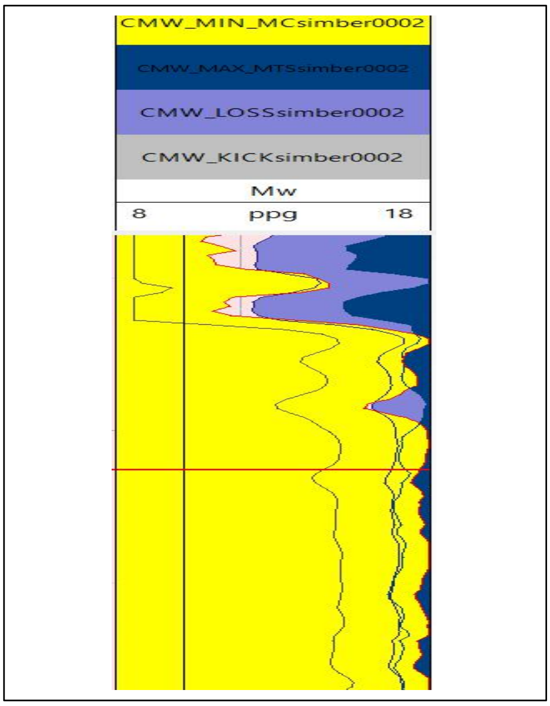

Figure (4.22): Range of optimum mud weight for (BE)

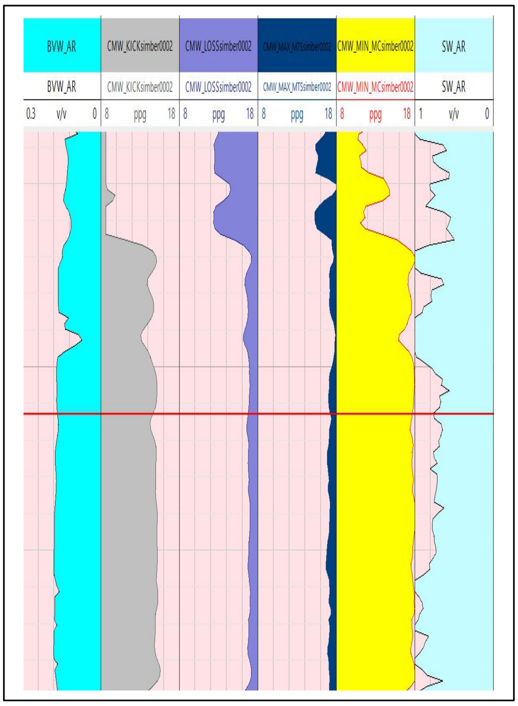

Figure (4.23) : The range of (kick , losses ,Breakdown, shear failure, water saturation) for (BE)

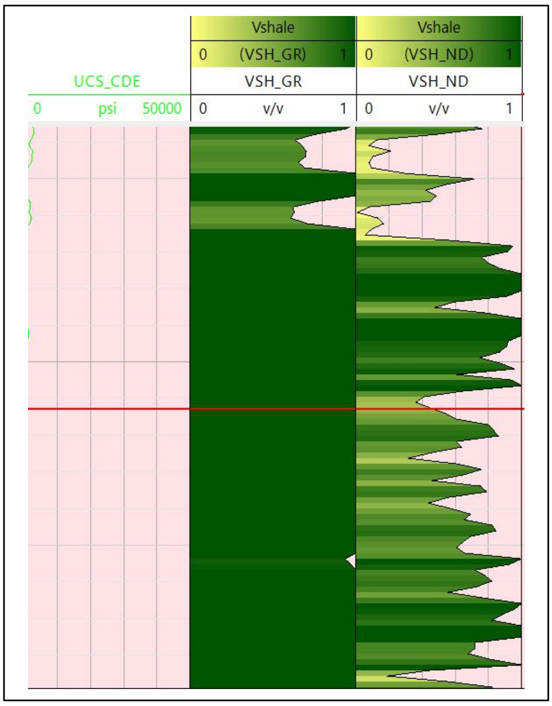

Figure (4.24) : Shale Volume (VSH) from (GR ,ND) in (BE)

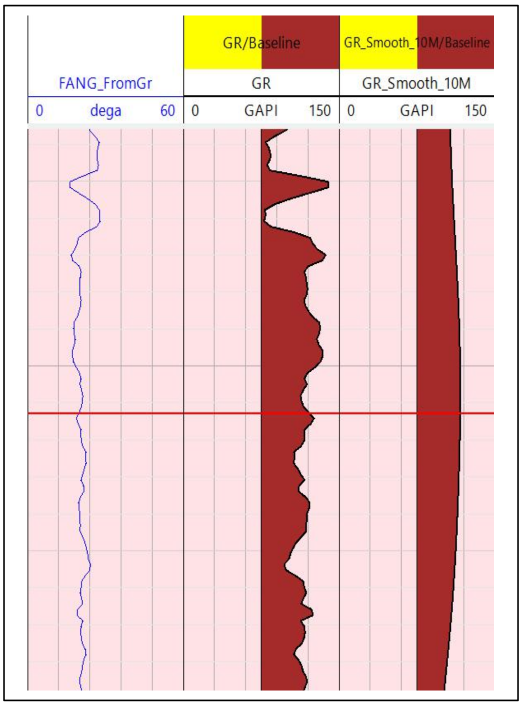

Figure (4.25) :the range of sand and shale for (BE)

The description of the graphs in BENTIU zone which is from the depth for discuss is 2826 m :

Figure (4.22) : show that there was a high risk of fluid loss and breakdown when drilling with Mw > 12.92 ppg , as well as shear failure when drilling with Mw < 17.44 ppg , and the mud weight that used (Mw = 10.2ppg) which it is located at the range of shear failure risk , all the zone exposure to shear failure if we use this mud weight,but if the mud weight exceed 16.31 ppg that will lead to breakdown, so the proper solution is to use LPM application in order to avoid the risk of shear failure and breakdown.

Figure (4.23) : show that the range of risks individual , when the kick < 15.31 ppg , shear failure < 17.44 , losses > 12.92 , Breakdown > 16.31 , the water saturation and formation fluid volume are very high so that mean there are high support for the formation that lead to high risk of shear failure(high formation pressure) .

Figure (4.24) : show the shale volume from both (gamma ray log ,neutron density log), and both logs show a high quantity of shale that increase the risk of collapse and stuck .

Figure (4.25) : show the gamma ray indication of zone according to sand shale percentage, there was dominance of shale in this zone(only shale) .

From the Geomechanical earth model : show that BE formation is conceder as a shale formation with some thin layers of sand do not exceeds the normal limit (shale formation) which has been confirmed by (GR , ND) logs , that indicate to high shale volume . The model also show very high risk of shear failure ,with low risk of fluid losses. And there is some layer have a risk of losses , and to avoid that we need to apply the LPM Design to drill with a high mud weight through this shale layer without breaking the thin sand layer .

4.2 Lost Preventive Materials (LPM) Design :

From the data that obtained from the Earth Geomechanical Model , Lost Preventive Materials Design can be done by calculate the FRACTURE WIDTH , PARTICLE SIZE DISTRIBUTION using the equations (49), (55), with the data (Pore pressure, Depleted interval depth, Wellbore pressure, Hole diameter & Fracture Length, Poisson's Ratio, Young's Modulus, Minimum & maximum horizontal stress) .

4.2.1 LPM Design For Zone In (AM SS) Formation :

The weak zone that required and LPM Design in AMAL formation is located between the depths (800 - 835.9 m) and its data :

Table (4.1): Data of the AM SS Zone

Parameters	Value	
Depth	800	835.9
Young's ratio	319428.5	1,127,217
Poissen ratio	0.4637	0.3826
Minimum horizontal stress	2251	2375
Hole diameter	12.5	12.5
Fracture length	6	6
Radius	6.25	6.25
X=L-R	0.25	0.25
Density	9.5	9.5
Surface pressure	1700	1700

From the equation (3.51) :

Fracture Width = **0.4189335 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **398.19 in.Ib/bbl** LPM Concentration = **26.78 Ib/bbl**

And for the other parts of the (MA SS) formation : at the depth (835.9 - 959 m) we should use a mud weight about 11.55 ppg , and at the depth (959 - 1061 m) we should use a mud weight about 12.50 ppg , to avoid all the risk that related with losses , breakdown and shear failure .

4.2.2 LPM Design For Zones In (BA SS) Formation :

The first weak zone that required a LPM Design in BARAKA formation is located between the depths (1081.4 - 1087.8 m) and its data :

Table (4.2) : Data Of the BA SS First Zone

Parameters	Value	
Depth	1081.4	1087.8
Young's ratio	1324528	2917580
Poissen ratio	0.37	0.4
Minimum horizontal stress	3390.8	3217.2
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.5	9.5

From the equation (3.51) :

Fracture Width = **0.09079 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **86.3 in.Ib/bbl** LPM Concentration = **1.655 Ib/bbl**

The Second Weak Zone that required a LPM Design in (BA SS) formation is located between the depths (1327.7 - 1338.4 m) and its data :

Table (4.3) : Data of the BA SS second zone

Parameters	Value	
Depth	1327.7	1338.4
Young's ratio	1622692	2412099
Poissen ratio	0.42	0.38
Minimum horizontal stress	4665	4741
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.6	9.6

From the equation (3.51) :

Fracture Width = **0.07072 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **67.22 in.Ib/bbl** LPM Concentration = **1.009 Ib/bbl**

The Third Zone that required a LPM Design in (BA SS) formation is located between the depths (1364.8 - 1382.4 m) and its data :

Table (4.4) : Data of the BA SS third zone

Parameters	Value	
Depth	1364.8	1382.4
Young's ratio	3582218	2950302
Poissen ratio	0.39	0.38
Minimum horizontal stress	4694	4676.7
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.6	9.6

From the equation (3.51) :

Fracture Width = **0.040408 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **38.40 in.Ib/bbl** LPM Concentration = **0.3325 Ib/bbl**

The Forth Zone that required a LPM Design in (BA SS) formation is located between the depths (1670.8 - 1692.4 m) and its data :

Table (4.5) : Data of the BA SS Forth zone

Parameters	value	
Depth	1670.8	1692.4
Young's ratio	3561487	2239657
Poissen ratio	0.06	0.38
Minimum horizontal stress	6010.6	5990
Hole diameter	9.875	9.875
Fracture length	6	6

Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.7	9.7

From the equation (3.51) :

Fracture Width = **0.05323 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **50.59 in.Ib/bbl** LPM Concentration = **0.574 Ib/bbl**

And for the other part of the BA SS Formation : The another depths along the formation except the part that need LPM design we should use a mud weight range between (9 - 10.72) ppg , to avoid all the risk that related with losses , kick , breakdown and shear failure .

4.2.3 LPM Design For Zones In (GH) Formation :

The zone that required and LPM Design in GAZALA formation is located between the depths (1926 - 1929 m) and its data :

Table (4.6) : Data of the GA zone

Parameters	value	
Depth	1926	1929
Young's ratio	1926337	2722140
Poissen ratio	0.34	0.218527
Minimum horizontal stress	6003.66	6027.9
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.7	9.7

From the equation (3.51) :

Fracture Width = **0.06397 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **60.8 in.Ib/bbl** LPM Concentration = **0.827Ib/bbl**

And for the other part of the GH Formation : The another depths along the formation except the part that need LPM design we should use a mud weight about (11.25) ppg , to avoid all the risk that related with the losses , kick , breakdown and shear failure .

4.2.4. LPM Design For Zones In ZA Formation :

The First Zone that required a LPM Design in ZA Formation is located between the depths (2025 - 2087 m) and its data :

Table (4.7) : Data of the ZE First zone

Parameters	Value	
Depth	2025	2087
Young's ratio	1989412	1291118
Poissen ratio	0.408080	0.3996529
Minimum horizontal stress	6369.8	6574.9
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.7	9.7

From the equation (3.51) :

Fracture Width = **0.0899 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **85.49 in.Ib/bbl** LPM Concentration = **1.62 Ib/bbl**

The Second Zone that required a LPM Design in ZA formation is located between the depths (2218 - 2262 m) and its data :

Table (4.8) : Data of the ZA Second formation

Parameters	Value	
Depth	2218	2262
Young's ratio	1022892	931203.3
Poissen ratio	0.473	0.476
Minimum horizontal stress	6917.76	7150.74
Hole diameter	9.875	9.875
Fracture length	6	6

Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.7	9.7

From the equation (3.51) :

Fracture Width = **0.1057 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **100.49 in.Ib/bbl** LPM Concentration = **2.23 Ib/bbl**

The **Third Zone** that required a LPM Design in ZA formation is located between the depths (2343 - 2399 m) and its data :

Table (4.9) : Data of the ZA Third zone

Parameters	Value	
Depth	2343	2399
Young's ratio	348186.1	3207462
Poissen ratio	0.481	0.139921
Minimum horizontal stress	7472.38	7677
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.7	9.8

From the equation (3.51) :

Fracture Width = **0.3075 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **292.35 in.Ib/bbl** LPM Concentration = **18.33 Ib/bbl**

The **Forth Zone** that required a LPM Design in ZA formation is located between the depths (2408 - 2435.8 m) and its data :

Table (4.10) : Data of the ZA ourth zone

Parameters	value	
Depth	800	835.9
Young's ratio	319428.5	1,127,217
Poissen ratio	0.4637	0.3826
Minimum horizontal stress	2251	2375

Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.5	9.5

From the equation (3.51) :

Fracture Width = **0.0712 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **67.68 in.Ib/bbl** LPM Concentration = **1.022 Ib/bbl**

The Fifth Zone that required a LPM Design in ZA formation is located between the depths (2470.6 - 2720 m) and its data :

Table (4.11) : Data of the ZA Fifth zone

Parameters	Value	
Depth	2470.6	2720
Young's ratio	1598776	1643080
Poissen ratio	0.418	0.4619
Minimum horizontal stress	7924.4	8746.9
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.8	9.8

From the equation (3.51) :

Fracture Width = **0.07191 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **68.36 in.Ib/bbl** LPM Concentration = **1.043 Ib/bbl**

And for the other parts of the formation : at the depth (1932 - 2025 m) we should use a mud weight between (10.2 - 11.25) ppg , and at the depth (2087 - 2218 m) we should use a mud weight about 11.44 ppg , and at the depth (2262 - 2343 m) we should use a mud weight about 11.78 ppg ,and at the depth (2399- 2408 m) we should use a mud weight about 11.78 ppg , and at the depth (2435 - 2470 m) we should use a mud weight about 11.78 ppg , and at the depth (2720 - 2752 m) we should use a mud weight about 11.14 ppg , to avoid all the risk that related with losses , breakdown and shear failure .

4.2.5 LPM Design For Zones In AR Formation :

The weak zone that required and LPM Design in AR formation is located between the depths (2753 - 2790 m) and its data :

Table (4.12) : Data of the AR zone

Parameters	value	
Depth	2753	2790
Young's ratio	929394	389331
Poissen ratio	0.458	0.4648
Minimum horizontal stress	8842.8	8987.32
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	9.8	9.8

From the equation (3.51) :

Fracture Width = **0.2805 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **266.65 in.Ib/bbl** LPM Concentration = **15.3 Ib/bbl**

All the depth of the formation is required and need a LPM Design to avoid all the risk that related with breakdown (when drilling with recommended high mud weight) according to the high risk of shear failure to avoid the proplem of breaking the formation .

4.2.6 LPM Design For Zones In BE Formation :

The First Zone that required a LPM Design in BE formation is located between the depths (2804 - 2925.8 m) and its data :

Table (4.13) : Data of the BE First zone

Parameters	value	
Depth	2804	2925.8

Young's ratio	2496233	909027
Poissen ratio	0.3789	0.4671
Minimum horizontal stress	9021.15	9508.56
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	10.2	10.4

From the equation (3.51) :

Fracture Width = **0.11983 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **113.9 in.Ib/bbl** LPM Concentration = **2.865 Ib/bbl**

The Second Zone that required a LPM Design in BE formation is located between the depths (3029.7 - 3041.16 m) and its data :

Table (4.14) : Data of the BE Second zone

Parameters	Value	
Depth	3029.7	3041.16
Young's ratio	3282989	2492307
Poissen ratio	0.403	0.3527
Minimum horizontal stress	9601.3	9970.5
Hole diameter	9.875	9.875
Fracture length	6	6
Radius	4.9375	4.9375
X=L-R	1.0625	1.0625
Density	10.4	10.4

From the equation (3.51) :

Fracture Width = **0.04895 in**

From the equation (3.55) and (3.57) :

Practicals Size Distribution = **46.53 in.Ib/bbl** LPM Concentration = **0.4865 Ib/bbl**

And for the other parts of the formation : at the depth (2925.8 - 3029.7 m) we should use a mud weight about (11.7) ppg , and at the depth (3041.16 - 3121.34 m) we should use a mud weight between(11.22 - 11.86) ppg , to avoid all the risk that related with losses , breakdown and shear failure .

Chapter 5

Conclusion & Recommendations

5.1 Conclusions :

- Wellbore instability analysis results from SW formations (AM, BA, GH, ZA, AR, BE).
- Mechanical properties of the rocks as well as stresses has been defined to clear understanding of rock behavior.
- Commercial software results show the risk of (fluid losses, breakdown, shear failure, kick) for each layer to provide the optimum range for selecting the suitable mud weight .
- The analysis of the result from the Earth Geomechanical Model show that AM formation have risk of high fluid losses, and BA formation have risk of shear failure , and GA formation have risk of fluid losses, and ZA formation have varying risk of shear failure and fluid losses, and AR formation have risk of shear failure, and BE formation have high risk of shear failure .
- The analysis also show the shale volume, and type of formation (sand , shale) , and water saturation from both (gamma ray log ,neutron density log).
- The recommended mud weight was recognized for each zone , (10.82 -11.86)ppg for AM ,(8.5 - 12.35)ppg for BA ,(9.3 - 11.53)ppg for GA ,(11.78 - 12.9) ppg for ZA , (10.90 - 11.86) ppg for AR ,(11.22 - 11.86) ppg for BE.
- Lost Preventive Materials (LPM) Design was applied for the weak formations to avoid the detected risks in the formation and high cost treatment .
- For each weak zone in any formations the (fracture width, particle size distribution , LPM concentration) was calculated .

5.2 Recommendation and Future Work :

5.2.1 Recommendation :

- Fractures must be opened slowly and in a controlled manner to allow the bridge to form at the mouth .
- Must avoid sudden hydrostatic transients above the previously created stress states .
- The recommended mud weight should be applied carefully to avoid the formations damages as much as we can .
- For more accurate results, LPM model should be updated by select proper materials (better to be local materials) .

5.2.2 Future Work :

- The plugging materials will be produced from a local materials (Sudanese materials) .
- Laporatery experiment should be done for variate materials to build a guide that will help to select optimum LPM materials and give the required data about this materials that uesd to calculate the LPM concentration.

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