A Case Study of Geomechanical Modeling and Wellbore Stability Analysis in the Vicinity of Naga Thrust Area in the Upper Assam Basin

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Geomechanical Modeling, Wellbore Stability, Thrust Area

Abstract

In the Upper Assam Basin, areas specifically near the Naga thrust belt are challenging for oil and gas exploration due to its complex geological settings, leading to high costs and risks associated with drilling. The Oligocene formation in this area is the main reservoir and is mainly composed of thick and highly compacted reservoir sandstone with some interbedded shale layers. The reservoir is sealed by overlain (Upper Oligocene formation) shale layer which contains a few strikes of sandstone and coal seams. The Upper Oligocene formation generally poses significant drilling challenges, viz. over-gauged borehole, tight pull, pipe stuck etc. Also, few drilling challenges have been observed in the overlying Miocene formation. These complications in turn increases Non-Productive Time (NPT) while drilling. Moreover, the over-gauged borehole and severe down-hole drilling complications result in poor logging condition and uncertainty in reservoir evaluation. In this study, a Mechanical Earth Model (MEM) has been generated, and wellbore stability analysis has been carried out using industry standard Geomechanics workflow to optimize mud weight in future wells, in order to reduce drilling complexities and also to reduce NPT.

Result of this study showed that the mud weight used for drilling in previous wells were less than optimal, causing shear failure and other drilling problems, especially in Upper Oligocene and Lower Miocene formation, indicating that the mud weight needs to be revised for the wells in Oligocene and Miocene formation. The findings of this study were incorporated into the design of future wells, which lead to completion of drilling operation with fewer complications. Also, the NPT for next wells were significantly reduced compared to earlier wells. In addition to that, due to enhanced logging condition, good quality logs could be recorded in the reservoir section and proper reservoir evaluation could be carried out.

Introduction

The study area is in the Upper Assam Basin and in the vicinity of Naga thrust belt. Before the inception of the study, five (05) wells were drilled in this area, namely W1, W2, W3, W4 and W5 out of which Well W1 is the only vertical well. All the wells suffered severe down-hole drilling complications (viz. over gauged hole, tight pull, pipe stuck etc.) in Upper Oligocene and Lower Miocene formation and the severity observed to be escalated with increasing deviation of the wells which in turn increased Non-Productive Time (NPT) while drilling. In order to tackle these challenges, it was crucial to develop a robust understanding of earth's mechanical/rock properties through Geo-mechanical models for the areas.

Study Area & Challenges

The present study area is bounded by WNW-ESE & NE-SW trending faults in north-east & north-west sides, respectively at Oligocene level. Whereas the surface trace of the Naga thrust lies in the south-east of the area (Figure 01).

This study has been focused mainly on the Oligocene and Lower Miocene formations. The Oligocene formation has been producing oil for more than a decade. It is subdivided into two parts as Upper & Lower Oligocene formations. The Lower Oligocene formation is predominantly composed of thick and highly compacted sandstone charged with hydrocarbon with some interbedded shales layers. The Upper Oligocene, overlying the producing formation comprises of shale with very few streaks of sandstone & coal seams. The overlying Miocene formation comprises of mainly sand-shale sequence. The Upper Oligocene and Lower Miocene layers generally pose significant challenges during drilling.

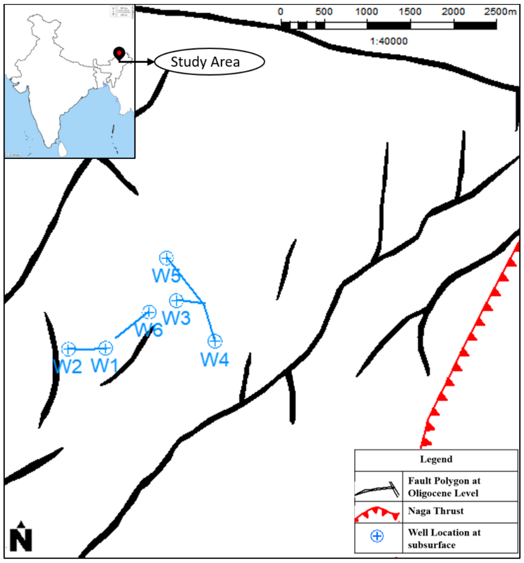

Figure 01: Base map of study area.

Figure 02 shows the comparison of the borehole shape of all the five wells, which depict the over-gauging of the wells due to drilling complications prior to this study. The drilling progress chart of Well W5 is shown in Figure 03 which gives an overview of all the drilling challenges (stuck-pipe, cavings, tight hole etc.) encountered in the well.

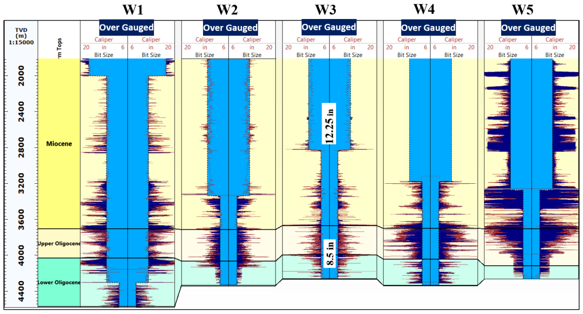

Figure 02: Borehole shapes of wells drilled in the study area.

Thus, the area as observed is prone to drilling complicacies. Furthermore, the upcoming wells were likely to have highly deviated trajectory owing to the limited land availability, thus increasing the likelihood of down-hole complications during drilling. Hence a detailed Mechanical Earth Model illustrating the rock strength and related stress fields was vital and considered it will definitely aid in solving the challenges.

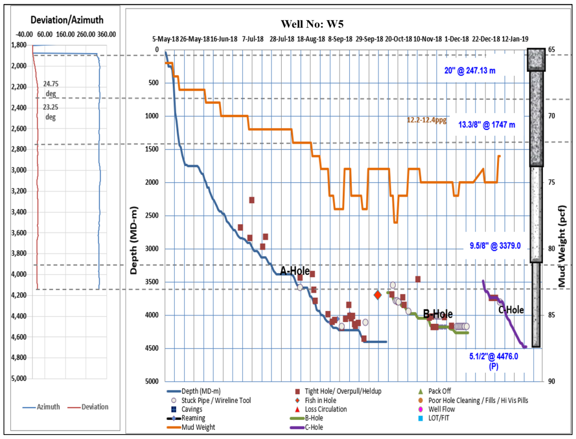

Figure 03: Drilling progress chart of well W5.

Theory & Method

1. Mechanical Earth Model Computation: In this study, Geomechanical model for two (02) wells (W2 and W3) have been developed in order to get better understanding about the area under investigation. For this, Mechanical Earth Model (MEM) for the wells have been prepared. The MEM is a numerical representation of the state of stress and rock mechanical properties for a specific stratigraphic section in a field or basin (Plumb et al; 2000). The MEMs for the wells were constructed by integrating drilling data, logging data, seismic data, formation pressure data, leak-off test (LOT) data, core data, major drilling events etc. using the workflow as shown in Figure 04. The MEMs were then taken as input in rock failure equation to predict stable mud weight window. Wellbore failure is then computed using the actual mud weight used in drilling and the predicted stable mud weight window. The computed failure is then compared with the actual failure observed in calipers and drilling events. The parameters for MEM are then iteratively optimized till a good match is observed between the computed failure and actual wellbore failure.

After successful computation and calibration of the MEM, Mud Weight Sensitivity Analysis was carried out incorporating the MEM and rock failure equations to compute the safe mud weight window for the changes of well azimuth and deviation for different depths.

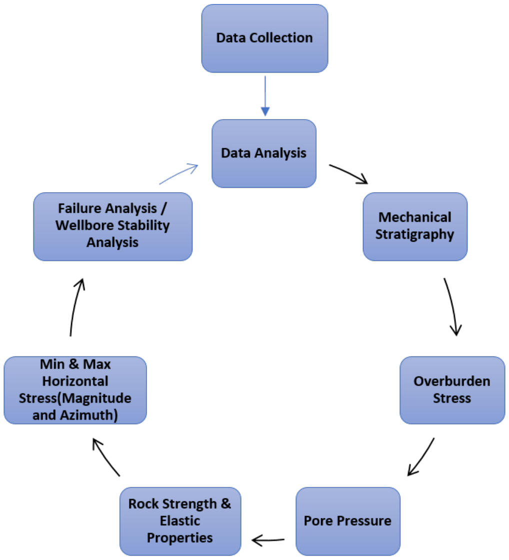

Figure 04: Workflow for MEM computation.

The important components/steps of the workflow are discussed below.

1.1 Overburden Stress: The overburden stress has been estimated using density log recorded at these well locations incorporating following empirical equation (Fjaer et al; 1992):

$$\sigma_z = \int_0^z \rho(z).g.dz$$

Where, σ_z is overburden stress, ρ is formation density and g is gravitational constant.

1.2 Pore Pressure: Pore Pressure is an important component in MEM, and critical to the calculation of horizontal stresses, wellbore stability analysis and other geomechanics applications (Reddy et al; 2017). Cross-plot of density versus compressional velocity data for Oligocene and Lower Miocene formation (Figure 05 A & B) has been used to understand the pore pressure mechanism.

No significant unloading trend has been observed in the cross plot (Figure 05 B) which indicates that undercompaction (Eaton, B.; 1975) is the only pore pressure mechanism in the area for Oligocene and Lower Miocene formation and hence, normal compaction trend of compressional slowness data can be used to compute the overpressure in the formation. Thus, pore pressure was computed based on Eaton's ratio Method (Eaton, B.,1975) using sonic log and subsequently, calibrated using recorded Shut-in Bottom Hole Pressure (SBHP) data at the wells, drilling events and other relevant information. Figure 06 shows the computed pore pressure for Well W2 and W3. In the Upper Oligocene formation, over pressure has been observed. The computed pore pressure was then calibrated with available recorded pressure data in the wells.

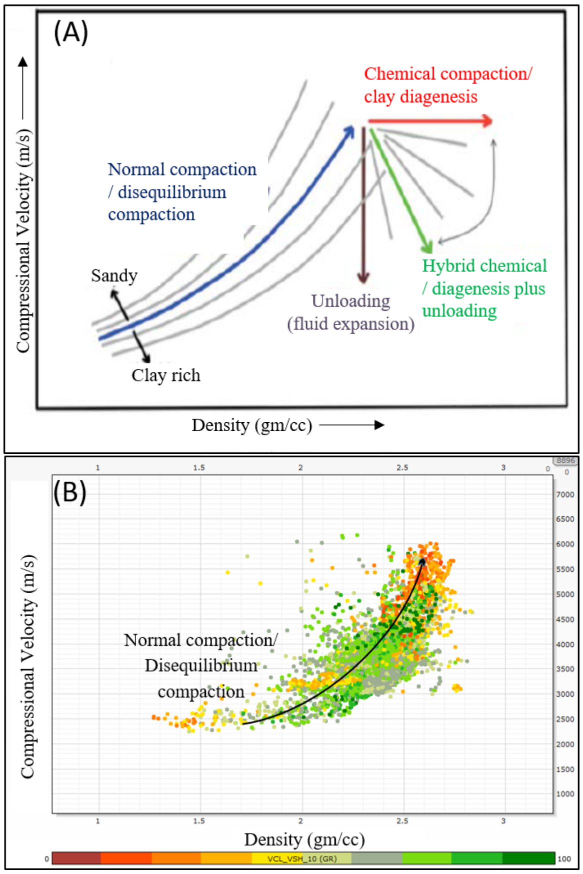

Figure 05:(A) Density versus compressional velocity plot (Hoesni, 2004). (B) Multiwell density-velocity crossplot for well W2 & W3.

1.3 Rock Strength & Elastic Properties Estimation: Using compressional and shear slowness logs data and bulk density log data, dynamic elastic properties were calculated. Dynamic rock elastic properties were then converted to static rock elastic properties using John Fuller correlations. In absence of rock mechanics core lab test results, static rock elastic properties were calibrated by examining the consistency in both the wells W2 and W3.

This information was then used to determine rock strength by virtue of which the rock withstand the in-situ stress environment around the wellbore. The rock strength can be defined based on UCS, Friction Angle & Tensile strength. These parameters were estimated and subsequently calibrated using available information at each well.

1.4 Horizontal Stress Magnitude: The overburden stress, pore pressure and rock elastic properties are taken as input into poro-elastic horizontal strain model (Fjaer et al; 1992) to compute horizontal stress magnitude.

$$\sigma_h = \frac{\nu}{1-\nu}\sigma_v - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_x + \frac{\nu E}{1-\nu^2}\varepsilon_y$$

$$\sigma_H = \frac{\nu}{1-\nu}\sigma_v - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\varepsilon_y + \frac{\nu E}{1-\nu^2}\varepsilon_x$$

Where, σ_h = minimum horizontal stress, σ_H = maximum horizontal stress, σ_V = overburden stress, α = Biot constant, Pp = pore pressure, ε_x = strain at minimum horizontal stress, ε_y = strain at maximum horizontal stress.

The stress profiles were calibrated with available LOT data and history match of predicted failures with caliper logs. Figure 06 shows the stress profiles in Well W2 and W3. The relative magnitude of horizontal stresses and vertical stress indicates normal fault regime in the vicinity of the wells under investigation.

1.5 Horizontal Stress Azimuth: Common stress azimuth indicators are breakouts and tensile failure as observed in image logs, directional calipers and shear sonic anisotropy as measured by shear sonic log. Of the two (02) wells considered, only Well W2 has image log and multi-arm caliper data for estimating horizontal stress azimuth (Figure 07). Based on the analysis of recorded image log and multi-arm caliper data, minimum horizontal stress direction is estimated as N108°±5°.

1.6 Failure Analysis / Wellbore Stability Analysis: The best way to calibrate the MEM is to verify the predictability of the model. Using the estimated rock properties and calibrated horizontal stresses, wellbore stability analysis tells us the accuracy of the MEM by comparing the predicted wellbore failure with the drilling events and observed hole condition from image and caliper logs.

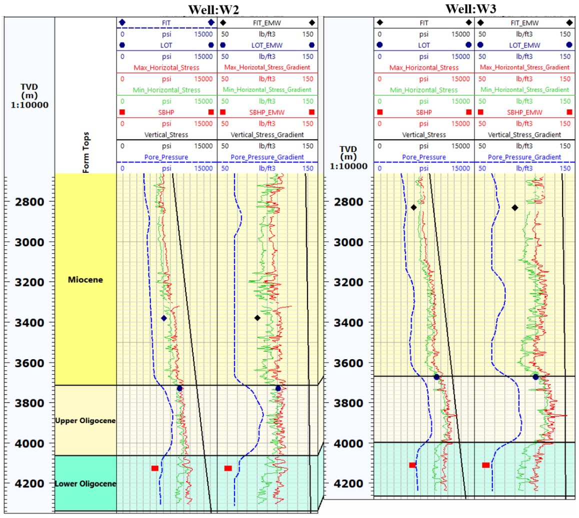

Figure 06: Pore Pressure, horizontal stresses (minimum and maximum) and Vertical stress for Well W2 and W3.

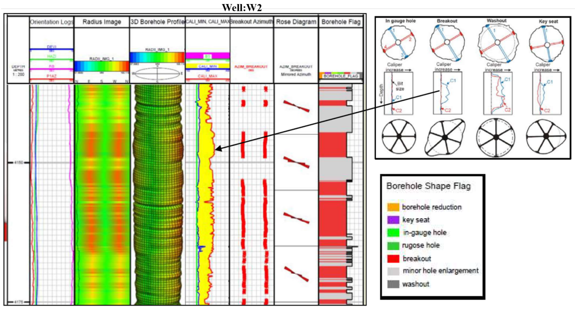

Figure 07: Image log and multi-arm caliper data of Well W2 for estimation of horizontal stress azimuth.

The MEMs were taken as input in rock failure equation to predict stable mud weight window. Wellbore failure is then computed using the actual mud weight used in drilling and the predicted stable mud weight window. The computed failure is then compared with the actual failure observed in calipers and drilling events. The parameters for MEM are then iteratively optimized till a good match is observed between the computed failure and actual wellbore failure. Figure 08 shows the final MEM (viz. rock elastic and strength properties, pore pressure and stresses etc.) and failure analysis of Well W2. A good match between the predicted failure and the caliper has been observed.

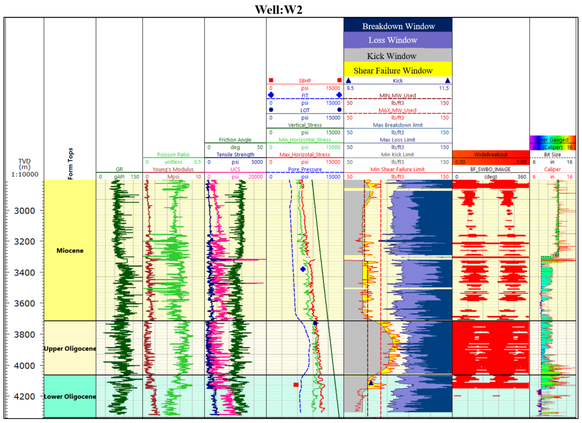

Figure 08: Calibrated MEM of Well W2 and Failure Analysis.

2. Mud Weight Sensitivity Analysis: Mud weights required to drill high angled deviated wells are sensitive on the well trajectory and deviation. The sensitivity analysis incorporates the MEM and rock failure equations to computes the safe mud weight window for the changes of well azimuth and deviation for different depths. The safe mud weight for Lower Miocene and Oligocene formation has been assessed with change of well deviation and azimuth. Figure 09(A), 09(B) and 09(C) shows sensitivity of mud weight window with well deviation as well as with azimuth at a certain depth for Lower Miocene, Upper Oligocene and Lower Oligocene formations respectively. It is understood from the analysis that the mud weight needs to be optimized for different formations with the changes of well deviation. However, for the formations under investigation in the study area, the safe mud weight window in not very sensitive to the changes in well azimuth.

Observations and Results

The study yielded several observations, which are listed below:

1. Minimum horizontal stress direction is estimated as N108°±5°.

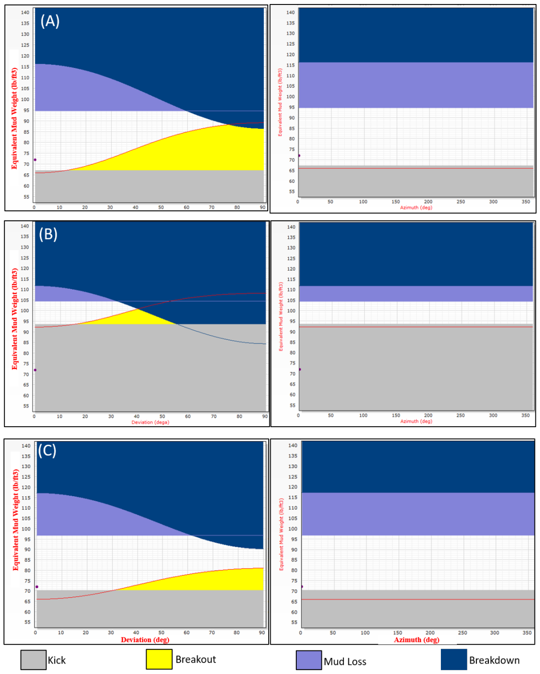

Figure 09: Mud weight sensitivity with well deviation and azimuth for (A) Lower Miocene, (B) Upper Oligocene and (C) Lower Oligocene formations.

2. 1D MEM for Well W2 which represents the Mechanical Earth Model of the area confirms the followings:

   I. UCS of Upper Oligocene formation is found to be very low compared to Lower Oligocene formation.
   II. Pore Pressure shows increasing trend in Upper Oligocene section (90-96 lb/ft^3) and further reversal in Lower Oligocene section (68-72 lb/ft^3).
   III. At all the wells, mud weight used to drill Upper Oligocene formation is less than optimum causing wellbore breakouts.

3. Shear failure in shales increases with bit runs and hole exposure for longer duration. Tight hole and tool stuck incidents are prominent in Upper Oligocene and Lower Miocene formations.

4. Mud weight optimization based on well deviation may help to minimize shear failure.

5. The upper Oligocene formation has high formation pressure and very low UCS compared to the overlying and underlying formations. Isolating the Upper Oligocene formation with a separate casing

may provide more flexibility to adjust mud weight while drilling to reduce the downhole drilling problems.

6. Based on the findings of the Geomechanical study, mud weight for the next well Well W6 has been optimized, which lead to successful drilling of this sixth well with fewer complications.

7. A comparison of bore hole shape of Well W5 and Well W6 is shown in Figure 10. A significant improvement in hole condition has been observed in Well W6.

8. Additionally, due to reduction of drilling complications, Non-Productive Time in Well W6 has significantly reduced as compared to Well W5 (Figure 11)

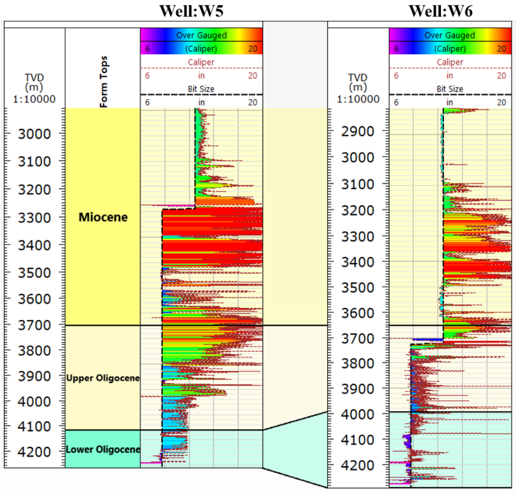

Figure 10: Comparison of bore hole shape for Well W5 and W6.

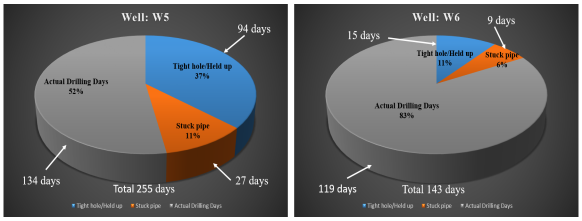

Figure 11: Comparison of actual drilling days and NPT for Well W5 and Well W6.

Conclusion

The study helped to understand the geomechanics of the study area by providing valuable insight into the subsurface conditions and mechanical state of the rock formations. This enabled us to identify potential drilling challenges and to develop effective strategies to mitigate them.

The findings of this study have been incorporated into the design of next well, which leads to completion of drilling operation with fewer complications. As a result, the NPT for next well has been significantly reduced compared to earlier wells. Also, due to enhanced logging condition, good quality logs could be recorded in the reservoir section for proper reservoir evaluation.

Reference

1. Plumb, T., Edwards, T., Pidcock, et al. "The Mechanical Earth Model Concept and Its Application to High-Risk Well Construction Projects." IADC/SPE Drilling Conference, New Orleans, Louisiana, USA, February 23-25, 2000. SPE-59128-MS.

2. Reddy, S. S., Anjaneyulu, J. V., Lal, A. K., Ramakrishna, C. H., Talreja, R., Bahuguna, S., Zacharia, J., Chatterjee, C., and Basu, J. "Geomechanics Aided Solutions for Improving Drilling and Completions by Integrating Advance Acoustics Measurements: A Case Study from Malleswaram Field, Onshore KG-PG Basin, India." 20th Middle East Oil & Gas Show and Conference (MEOS), Manama, Bahrain, March 6-9, 2017. SPE-183992.

3. Eaton, B. "The Equation for Geopressure Prediction from Well Logs." SPE Technical Conference and Exhibition, Houston, Texas, USA, September 21-24, 1975. SPE-5544.

4. Hoesni, M. J. "Origin of Overpressure in the Malay Basin and Its Effect on the Petroleum System" (PhD thesis). University of Durham, 2004.

5. Fjaer, E., Holt, R. M., Horsrud, P., Raaen, A. M., and Risnes, R. "Petroleum Related Rock Mechanics."

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