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Author Rajeev Kumar , Schlumberger Asia Services Ltd. , India
Co-Authors S.S.Reddy, J. V Anjaneyulu, C. H Ramakrishna, Rahul Talreja, Joseph Zacharia, Ravi Gondalia, Chandreyi Chatterjee and Ujjwal Nand

Advanced acoustic based geomechanics aids improvement in drilling to stimulation for tight unconventional reservoir

Abstract

Mandapeta field is located in KG basin with proven gas reserves in Mandapeta formations of Triassic age. The field is undergoing a fast-track development campaign, wherein wells have witnessed NPT due to various drilling challenges such as tight hole, stuck pipe etc. Bad borehole condition has affected the data quality being recorded for formation evaluation. Most of these drilling problems are reported in Raghavapuram, Gollapalli and Mandapeta Formations. Presence of faults and higher horizontal tectonic leads to the requirement of higher mud weight. With the increase in well deviation, stable mud weight window becomes narrow and required mud weight to prevent shear failure ranges between 1.45sg-1.55sg depending on well azimuth. Advanced acoustic measurements have been recorded in recent wells providing near-wellbore and far-field stress profile to calibrate local stress regime and rock mechanical properties. 1D Mechanical Earth Models (MEMs) have been constructed for different wells in the area to develop a geomechanical understanding of the reservoir as well as in the overburden and underburden layers. Anisotropic stress profile has been also built for high gamma ray and high resistivity (HG-HR) shale layer to check feasibility of hydro-fracturing. History match of predicted failures using 1D MEM with caliper and drilling events suggest that shales are relatively weaker than sands in both Gollapalli and Mandapeta Formations with variation of stress regime laterally. There is clear stress barrier at transition of Gollapalli to Mandapeta formation. Anisotropic stress profile in higher TOC content HG-HR Ragahvapuram layer provides better resolution of closure pressure and improved fracture design. New deviated well drilled with recommended mud weight~1.50sg at 30deg deviation has much better hole condition and rig days have been saved as compared to planned timeline. Hydro-fracturing results with pressure history match validates stress barriers and profile as predicted using advanced Geomechanical properties.

Introduction

Mandapeta field has high gas accumulations and is in the East Godavari district of KG-PG basin. Targets reservoir of these wells are tight and require unconventional techniques to expediate the huge hydrocarbons. Different challenges have been faced while drilling and hydraulic fracturing operations. This paper summarizes these challenges and provides current learnings based on acquired advance acoustic data.

A comprehensive geomechanical model makes it feasible to assess the drilling risks and facilitates by minimizing the impact of geomechanical problems, which will help to reduce the cost and time of the drilling operation. The key requirement for any geomechanics analysis is the construction of a MEM. The MEM is a numerical representation of the state of in-situ stress and rock mechanical properties for a specific stratigraphic section in a field or basin. It includes rock elastic and strength properties, pore pressure and in-situ earth stresses. Once the MEM is rigorously validated, it can be used to identify geomechanical problems during drilling and to devise contingency plans for the planned wells. It is done by conducting a wellbore stability analysis taking MEM as input. Wellbore stability analysis serves multiple purposes as not only it helps to validate the MEM but also assist in estimation of stable mud weight window. Estimated stable mud weight window can be used to estimate optimum mud weight program and casing setting depths along the well trajectory.

During drilling operations targeting Mandapeta formation reservoir in vertical and deviated wells, wellbore stability remained one of the major concerns. Major drilling problems included breakouts/cavings, stuck pipe, bad data quality etc., which increased nonproductive time (NPT), inflated the costs of drilling, and impacted the quality of critical formation evaluation data. The presence of high stressed sandstone layers together with low strength shale formations adds complexity for well design planning, drilling and logging. Wells drilled in the field have overgauged hole condition against these formations and NPT due to wireline tool stuck with cavings and tight holes. Borehole images clearly show wide breakouts in Gollapalli and Mandapeta Formations. Estimated pore pressure values range approximately 1.20gm/cc to 1.41gm/cc with increasing trend from top of Gollapalli formation. Measured SBHP inside Mandapeta sandstone at virgin condition also suggests 0.59psi/ft-0.63psi/ft. (1.36g/cc to 1.45gm/cc). To increase the gas production from target tight reservoir hydro-fracturing technique is adopted in few wells. To facilitate these operations advanced acoustic measurements have been acquired. Geomechanical input is the key for both drilling and hydro-fracturing design.

In the current study, post-drill MEMs for five offset wells are constructed with history matching of drilling events, calipers, images against MEM based predicted failures. Sonic shear radial profiles with stiffness matrix are used to constrain tectonics in the field, providing more reliable calibration method. MEM outputs are utilized to plan and execute the hydraulic fracturing (HF) operations. Closure pressure and breakdown pressure from HF results in early wells came close to predicted ones with one anomaly due to proximity of fault.

Concept of Wellbore Stability Analysis

Prior to drilling a well, the initial state of existing compressive stress in the rock formation can be resolved in three components: vertical stress (SigV), minimum horizontal stress (Sigh), and maximum horizontal stress (SigH). As the well is drilled, stress redistribution takes place near the rock with replacement of the initial support of drilled out rock by mud pressure. The redistributed stresses can be resolved in form of hoop stress acting circumferentially along wellbore and the radial stress and the axial stress acting parallel to the wellbore axis. With well deviation, the additional component of shear stress comes into play. If the rock strength is enough to sustain redistributed stresses, either in compression or tension, the wellbore will remain stable with the present mud weight. Hence, the computation of strength becomes a pivotal part of wellbore stability analysis. All geomechanical calculations have been done with assumption of linear elastic behavior.

Findings

- The overpressure mechanism appears primarily to be due to undercompaction based on compressional slowness and density plots (Hoesni, 2004) as shown in **Figure 1**. In addition, calibrated pore pressure profile shows that in shales pore pressure has an increasing trend with the increase in the porosity (**Figure 2**) supporting undercompaction theory. Calibrated pore pressure ramp starts from Raghavapuram shale bottom onwards.
- Stress induced anisotropy has been observed at few depth intervals where there is crossover of fast shear over slow shear radial profile. Maximum horizontal stress direction across field is in the N-S azimuth. Calibrated MEM suggests normal faulting stress regime (SigV > SigH >Sigh) with few strike slip local variation subject to presence of faults (**Figure 3, 4 and 5).**
- Borehole is enlarged throughout from Raghavapuram Formation to Gollapalli Formation. MEM suggest occurrence of both shear failure due to the use of relatively lower mud weight and minor washouts (**Figure 5**).
- Stress barrier is present near the transition of Gollapalli sandstone to Mandapeta formation. Even inside Mandapeta formation, estimated minimum horizontal stress /closure pressure varies depending on rock type. There is stress contrast of 1000psi-1500psi among good reservoir quality sandstone with potential shale barrier layers. Estimated breakdown pressure ranges between 7500psi-9000psi in good rock quality sandstone layers of Mandapeta formation with shale layer having 10500psi-11500psi values in Gollapalli formation. **Figure 6** shows the simulated fracture geometry with MEM inputs.
- Anisotropic stress model has also been constructed in another well-X where HG-HR shale layers of Raghavapuram Formation is the target. Transverse Isotropic vertical media (TIV) is present with Thomsen parameter Gamma in the range 0.34-0.95 (**Figure 7).**
- Anisotropic minimum horizontal stress profile captures the stress variation as compared to isotropic profile. There is a clear stress barrier at the transition to Gollapalli Sandstone Formation towards the bottom where stiff layers are present (**Figure 7)**. Even inside Raghavapuram formation, estimated minimum horizontal stress /closure pressure varies depending on rock type. There is stress contrast

of 600psi-1100psi among better rock quality HG-HR formation with potential barrier shale layers at top using anisotropic stress profile.

- Estimated breakdown pressure ranges between 7400psi-8600psi for HG-HR layers of Raghavapuram Shale Formation. Layers above the target zone have high stresses and will act as a barrier to HF growth. Estimated breakdown pressure for these layers is in the range of 9500psi-11500psi. This might vary subject to presence of weak planes if any.

Results and Conclusion

- Considering normal fault stress regime and stress contrast between horizontal stress profile, drilling high angled wells parallel to maximum horizontal stress azimuth (N-S) will require higher mud weight as compared to well-planned parallel to minimum horizontal stress azimuth (**Figure 8**).
- For a vertical well, mud weight can be lowered to 1.24sg-1.27sg while drilling Raghavpuram formation with proper hole cleaning measures and good flow rate to circulate out extra debris in low strength layers. This will reduce chances of drag and tool stuck with less mud overbalance across permeable layer. However, lower UCS and washout prone layers will require appropriate mud weight to minimize hole ovalization with increase in well deviation. In that case, appropriate additives must be added to minimize filter cake thickness across permeable layer (**Figure 7)**
- Mud weight required for preventing shear failure in the reservoir section is shown in the Table-1. Recently a deviated well was drilled with recommended mud weight (1.50sg at 30deg) with much improved hole condition, no major drilling events and saving rig days.
- Understanding developed has been utilized for recent hydro-fracturing jobs in the field. The first main fracturing job of well-B was an enormous success where a total of 154 MT of proppant was pumped and breaking the earlier record of 151 MT. The well is currently producing 50,000 m3/day gas from an initial no flow condition. The success story continued in well-D, where similar workflow was used and a record breaking 161 MT proppants was successfully placed in the Mandapeta Formation.

References

1. Eaton, B. A., 1975, the equation for geopressure prediction from well-logs: Society of Petroleum Engineers Paper 5544.
2. Bowers, G. L., 1994, Pore pressure estimation from velocity data: accounting for overpressure mechanisms besides undercompaction: International Association of Drilling Contractors/Society of Petroleum Engineers Drilling Conference, Society of Petroleum Engineers paper 27488, p. 515–530

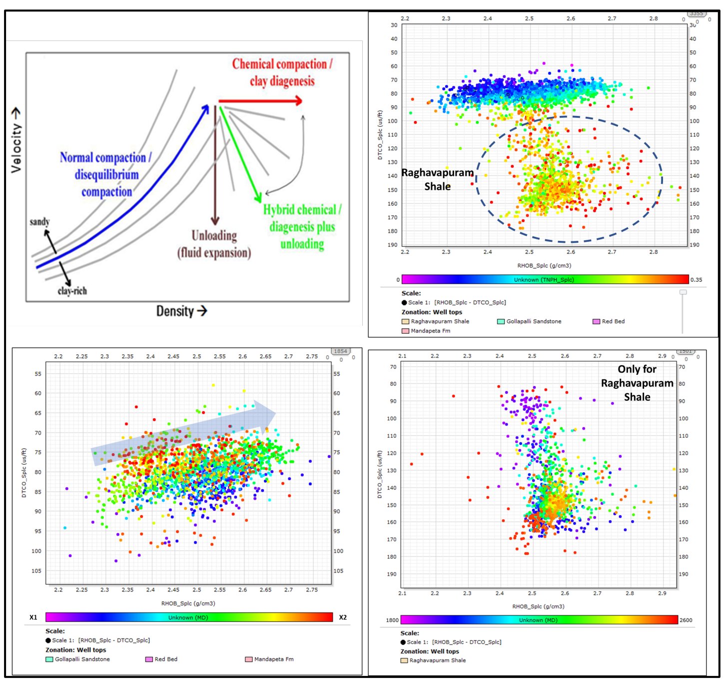

Figure 1- Hoseni plot: crossplot between compressional slowness and density in well-C

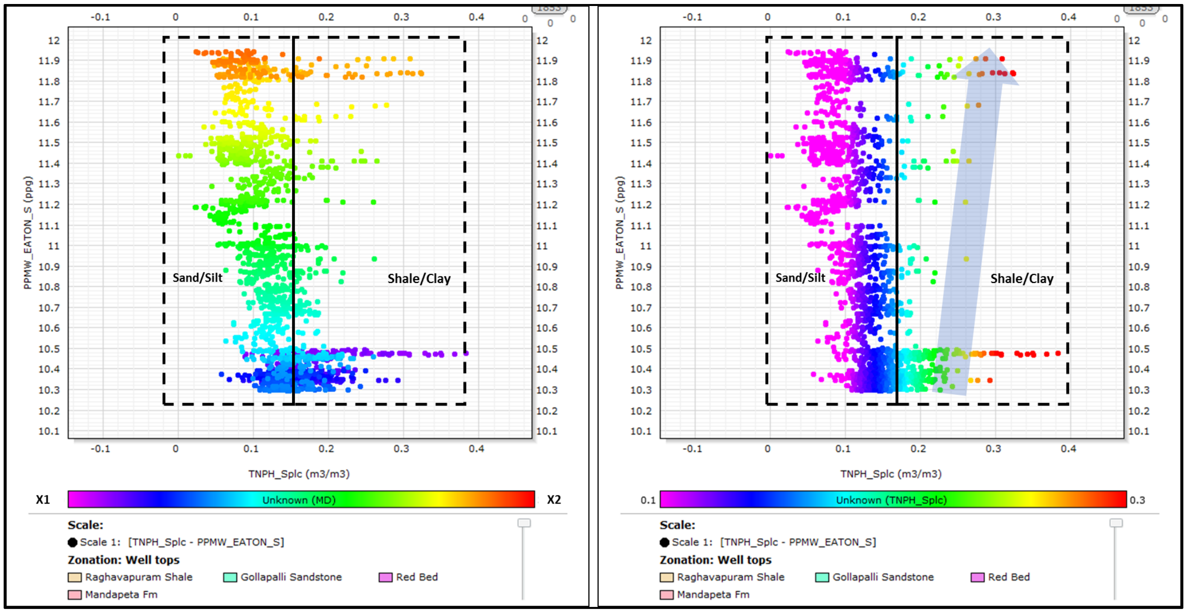

Figure 2- Pore pressure and porosity crossplot in well-C

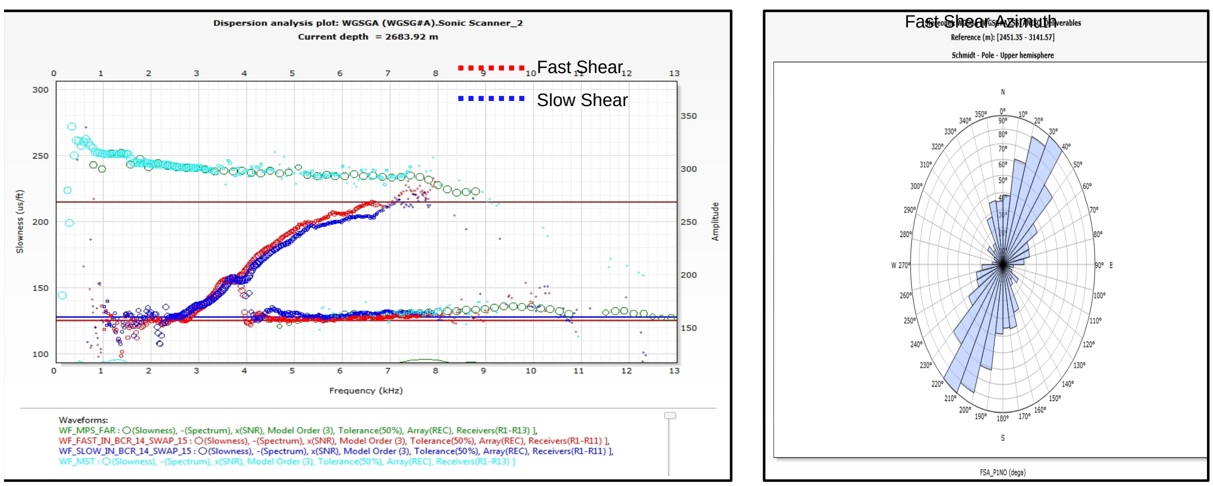

Figure 3: Fast Shear Azimuth from sowing maximum horizontal stress direction is NNE at well location

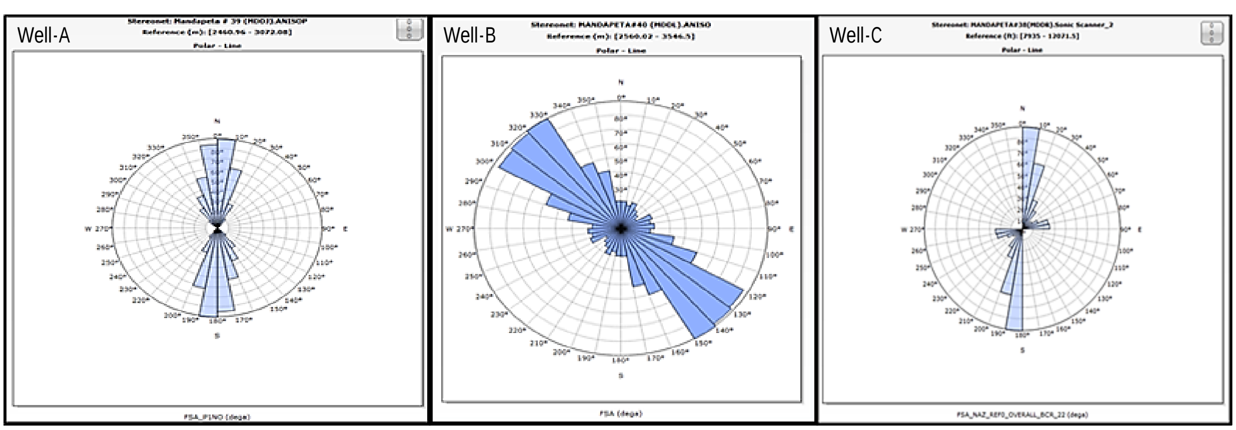

Figure 4: Variation of fast shear azimuth (FSH) across the field due to presence of faults

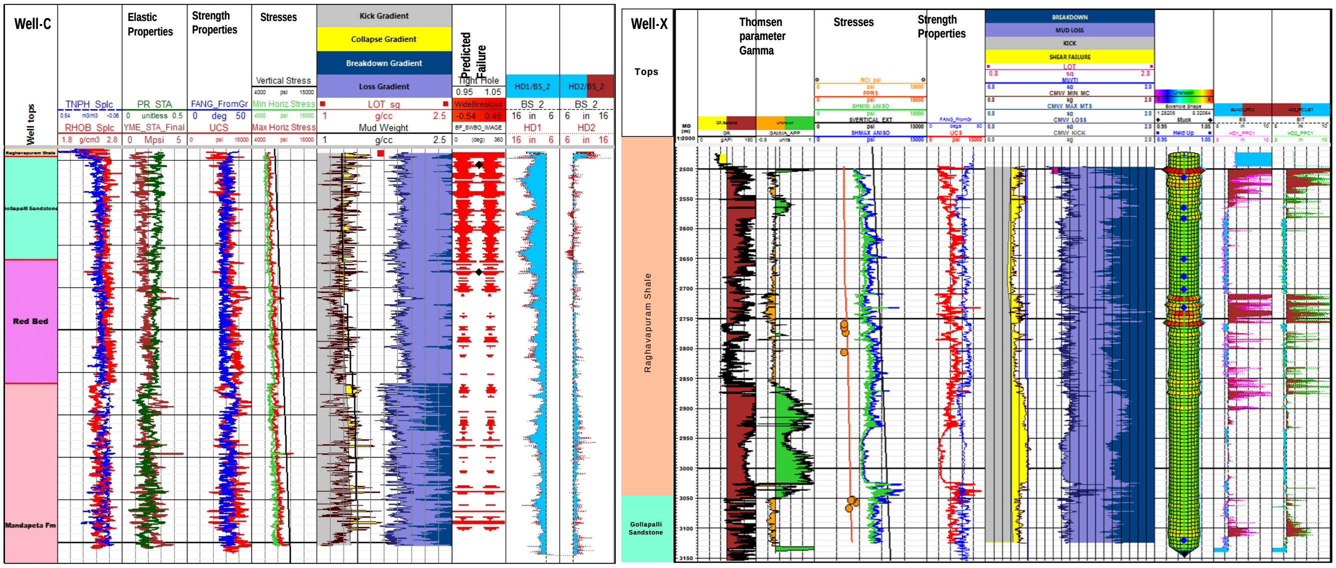

Figure 5: MEM Representation and wellbore stability analysis for well-C and well-X

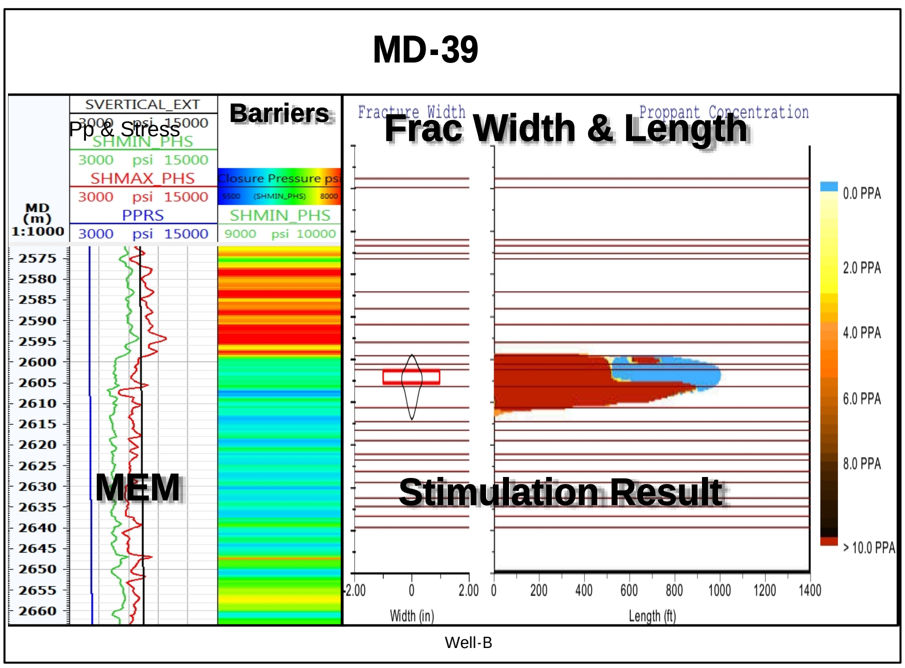

Figure 6: Initial simulation of hydrulic fracture based on MEM inputs for Mandapeta Sands

Table 1: Mud weight requirement for Target Formations

Formation	Vertical	Deviated (25deg)		Deviated (60deg)	
		N-S	E-W	N-S	E-W
Gollapillli	1.35SG-1.45SG	1.42SG-1.54SG	1.38SG-1.50SG	1.46SG-1.60SG	1.43SG-1.55SG
Mandapeta	1.45SG-1.51SG	1.53SG-1.58SG	1.48SG-1.55SG	1.57SG-1.63SG	1.52SG-1.58SG

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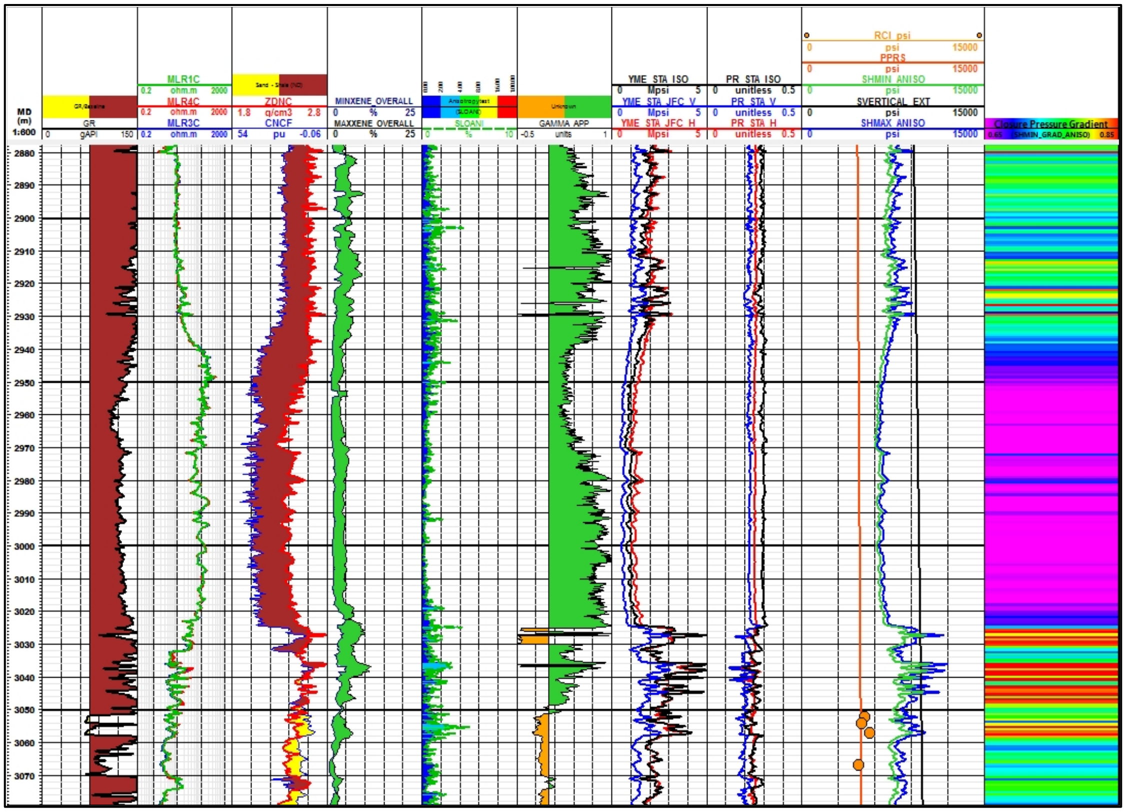

Figure 7: Variation of stress profile and CQ vs. rock quality inside HG-HR layer of Raghavapuram shale in well-X

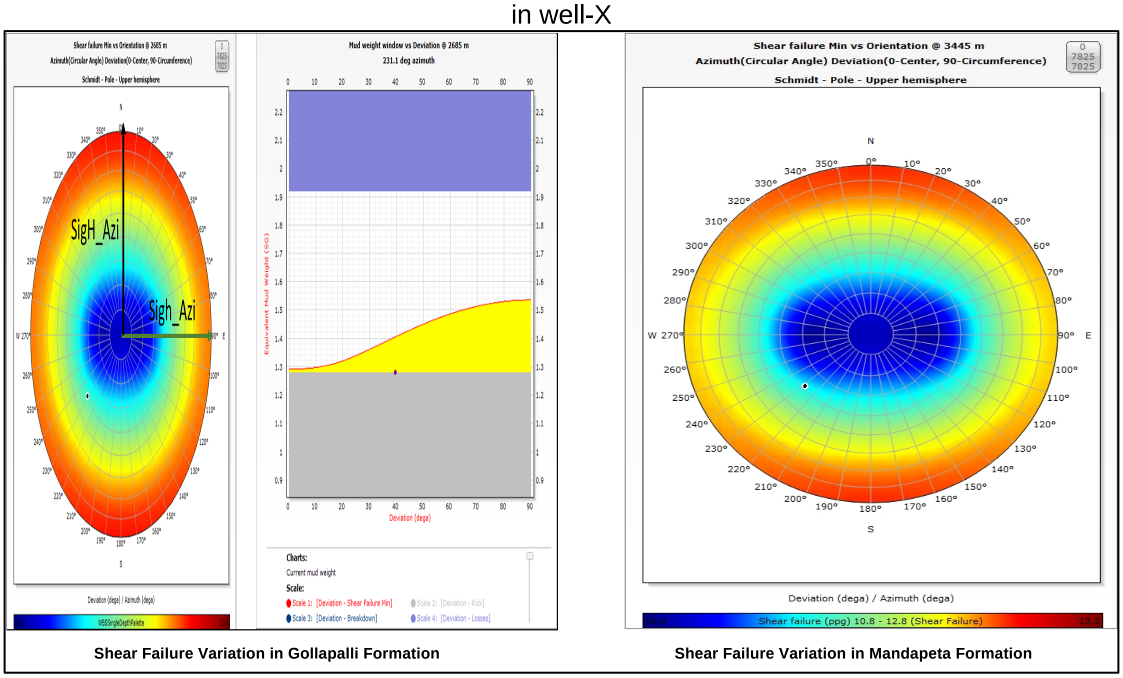

Figure 8: Trajectory Sensitivity Analysis in Gollapalli and Mandapeta Formation in well-C