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# Drilling and Geomechanics Insight of Chinchini Formation, Mumbai Offshore Basin, India

## Abstract

Chinchini formation is the youngest formation (Upper Miocene to recent) and first formation from seabed while drilling in the Mumbai Offshore Basin (MOB) of India. Thickness of Chinchini Formation across the MOB varies from ~1000m-2200m. It primarily consists of soft and sticky clays prone to swelling with water based mud (WBM) and requires appropriate salinity and mud weight support while drilling. Typically, 20" casing shoe is set around 350m-450m before drilling further in shale till Lower Miocene (1100m-1500m). With almost no risk of well flow due to absence of permeable layer, mud weight in the range of 9.1ppg-9.7ppg is used while drilling to enhance ROP in range of 30m/hr-45m/hr. However, several events of tight hole during pulling out of drilling BHA, appearance of cavings and further held ups during wireline logging are reported. This causes an additional delay of 3-4 days in 17.5" section. To help in running of 13-3/8" casing, mud weight is often increased before in Chinchini formation to 10.3ppg-10.5ppg in WBM and 9.9ppg-10.3ppg for synthetic oil based mud (SOBM).

To develop a better understanding of Chinchini Formation and reduce NPT in drilling, logging and casing operations, a comprehensive study is carried out in 6 different areas of MOB. Study integrates geophysical log, petrophysical interpretation, drilling parameters and drilling events etc. Rock mechanics model comprising of mechanical properties, pore pressure and stress profile has been built for each area and calibrated by history matching with leak-off tests, breakouts and drilling events.

Typically pore pressure in shale layers is in the range of 8.6ppg-8.8ppg. Only one field in shelf region has measured pore pressure is around 11.5ppg in a shallow sandstone reservoir in Chinchini Formation. Primary reason for overpressure mechanism is identified to be undercompaction. Based on Geomechanical analysis, mud weight required to drill vertical well in Chinchini Formation with minimal mechanical shear failure ranges between 9.6ppg-10.3ppg. With increase in well deviation, mud weight requirement increases for shale layers e.g. 10.8ppg at 30deg. Review of clay interaction with mud weight suggests SOBM is helpful in inhibiting the swelling of shale and saving rig time with better ROP and lesser torque and drag while POOH. Review of BHA design suggests it has little contribution towards observed tight holes while pulling out. Estimated rock strength was used for comparison of drilling efficiency in few wells. It is observed that in few intervals, energy was dissipated in enlarging the hole rather than drilling ahead, leading to poor ROP.

Real-time monitoring of drilling and mud logging parameters was performed at two vertical and one low angle deviated wells ensuring successful section TD. Study helped in optimizing the mud type, its weight and casing policy in recent wells and has given deeper insight into the behavior of Chinchini Formation.

Recommendations from this study has successfully assisted ONGC in optimizing drilling in Chinchini Formation and will benefit future drilling in Western offshore basin. Proactive decisions aided by monitoring by Real-time Center engineers has already saved 6 rig days in three offshore wells. Study has generated the need of additional advance sonic logging in Chinchini Formation. Findings of this study can be further extended to shelf regions where Chinchini Formation contains reservoir sands.

## Introduction to Study Area

Six different areas have been taken for the study. These areas are shown in Figure 1a. All the areas are in shallow water region (Water depth<100m) of MOB. Analysis integrating geophysical, geological, drilling parameters and geomechanics has been performed to get better insight into the formation behavior.

## Geology of Chinchini Formation

Chinchini Formation is present throughout the Western Offshore Basin, India. The sediment cover overlying Ratnagiri/Bandra/Tapti Formation in various parts of the basin has been designated as Chinchini Formation. Its contact with underlying rock units is characterized by a regional unconformity mapped as seismic horizon H-1A.
The formation consists of greenish grey to bluish grey soft, sticky clays with frequent intercalations of shell debris. The basal part of the formation is represented by grey to greenish grey shales occasionally interspersed with thin limestone layers, particularly, in the areas, where it is underlain by Ratnagiri Formation. The depositional environment of this formation has been inferred to be shallow marine, varying from inner neritic to outer neritic. Based on analysis, Upper Miocene to Recent age has been assigned to this formation. General lithostratigraphy of MOB is shown in **Figure 1b**.

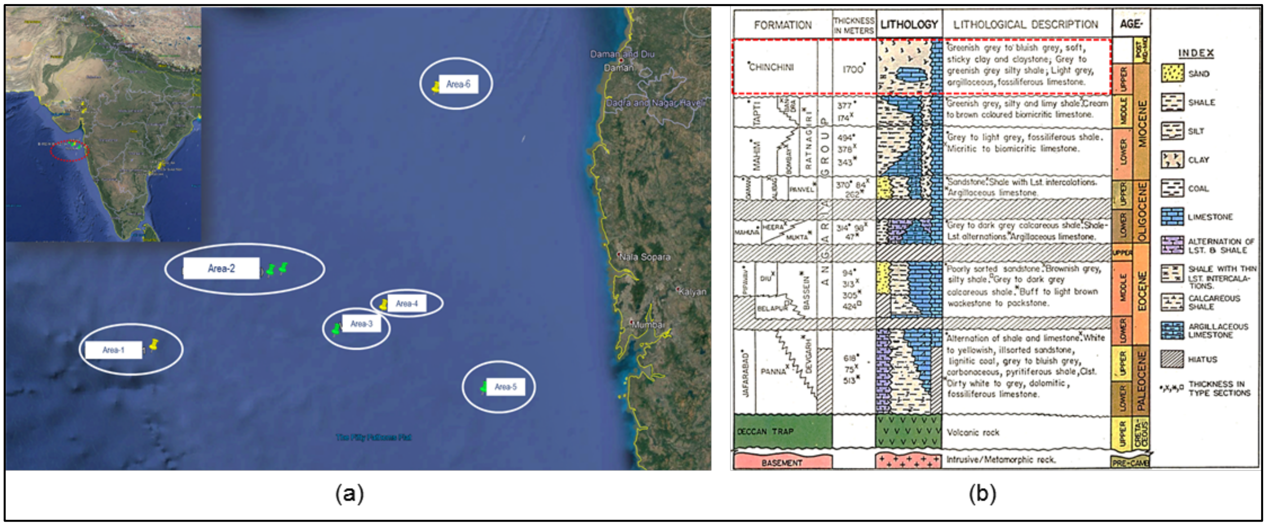



**Figure 1**:(a) Location and relative position of six areas under study (b) Lithostratigraphy of WOB

## Pore Pressure Variation in Chinchini Formation

Under-compaction is the primary reason for overpressure observed in Chinchini Formation. Figure 3 shows the cross plot between compressional slowness versus bulk density. Cross plot shows proportional relationship between the logs indicating under-compaction. Bowers plot (velocity versus effective stress) also indicates under-compaction where data points lying on loading curve. In this mechanism, with the rapid sedimentation, water present within the pore spaces of the sediment can't escape and is trapped under increasing overburden pressure during sediment loading. With this incomplete dewatering, part of the weight of the overburden load being added to the pore-fluid pressure. This mechanism is also called "disequilibrium compaction," and under this condition the rock will have higher porosity and pressure as compared to a normally pressured and fully compacted rock at the same depth. In this overpressure mechanism the key point is that the under-compaction will not take the pore pressure towards the overburden stress. Rate of increase in pore pressure and overburden stress can be same in case of a perfect impermeable seal and incompressible pore fluid, however it is not commonly observed.
Pore pressure fracture gradient (PPFG) models are constructed in the selected areas using compaction dependent geophysical properties (density, resistivity and sonic). Both Eaton's and Bowers method are used to construct the pore pressure.

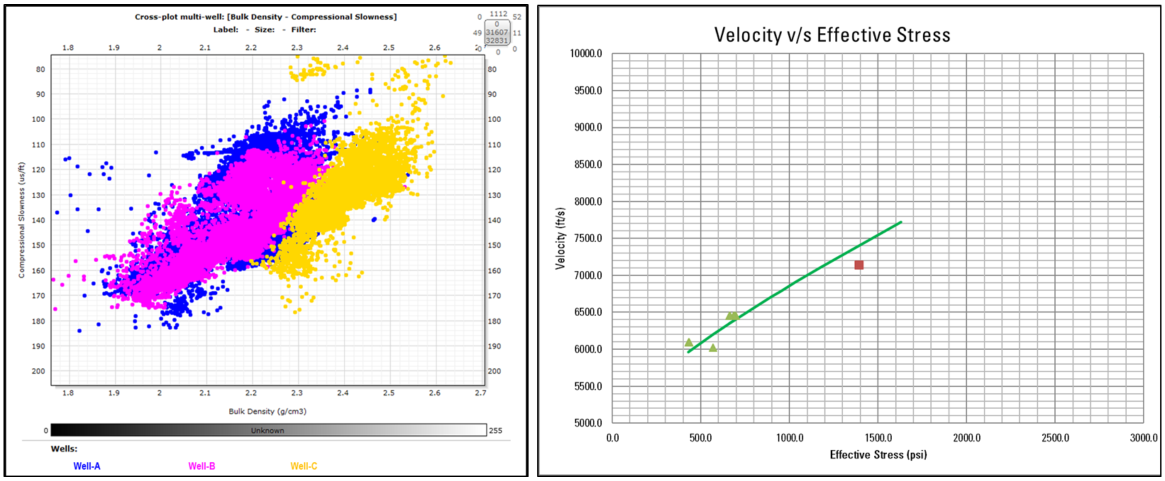


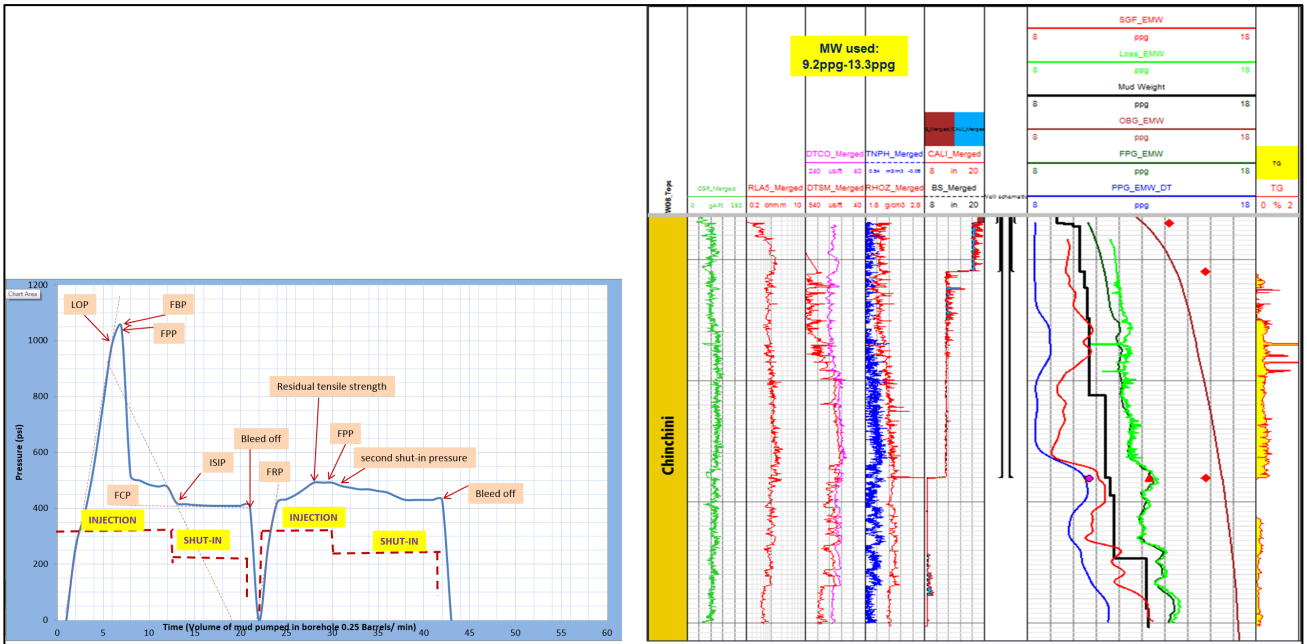

**Figure 2**: Compressional slowness versus bulk density crossplot. Crossplot shows proportional relationship between the logs indicating under-compaction (Modified after Hoesni, 2004). Bowers plot (velocity versus Effective stress) also indicates under-compaction where data points lying on loading curve. Bowers parameters for the best fit trend are A~8.5 and B~0.780.

## Analysis Summary

Comprehensive analysis has been performed in 6 different areas. In this section, 3 areas are discussed.

Area-1: It is in the Shelf region of the MOB where sands of Chinchini Formation are primary target. Chinchini Formation in this area is thicker (greater than 2000m) and its behaviour is found to be quite different from other areas. Among the 4 wells studied, MEM for two wells was constructed. Extended leak off tests performed in Chinchini Formation (Figure. 3a) reveals closure pressure of around 13.3ppg. Figure 3b shows the stable mud window plot for well-A drilled with KCl-PHPA water based mud system along with basic and sonic logs. Based on the analysis it is found that, maximum estimated pore pressure increases up to 11.4ppg in Chinchini Formation (Figure. 3b). Mud Weight used is on a higher side and ranges between ~9.2ppg to 13.3ppg.

Area-3: Total 4 wells are analyzed in this area. Figure 4a shows the comparison of borehole condition for wells drilled with water based mud (KCL-PHPA) and SOBM. Borehole is over-gauged in both the wells however; borehole condition is better in Well-B as compared to Well-A. In both the wells, drilling started with 8.6ppg which is later increased to 10.4ppg in well-A and 9.8ppg in well-B. MEM for well-B was prepared and is shown in Figure 4b. Mud weight used is below shear failure gradient and caliper log corresponding to that is also enlarged. Held ups/Tight spots are encountered while RIH and POOH operations in enlarged zones. Shear failure is touching 10.5ppg for a vertical wellbore and increases to 11.5ppg as shown in Figure. 5.




(a) (b)

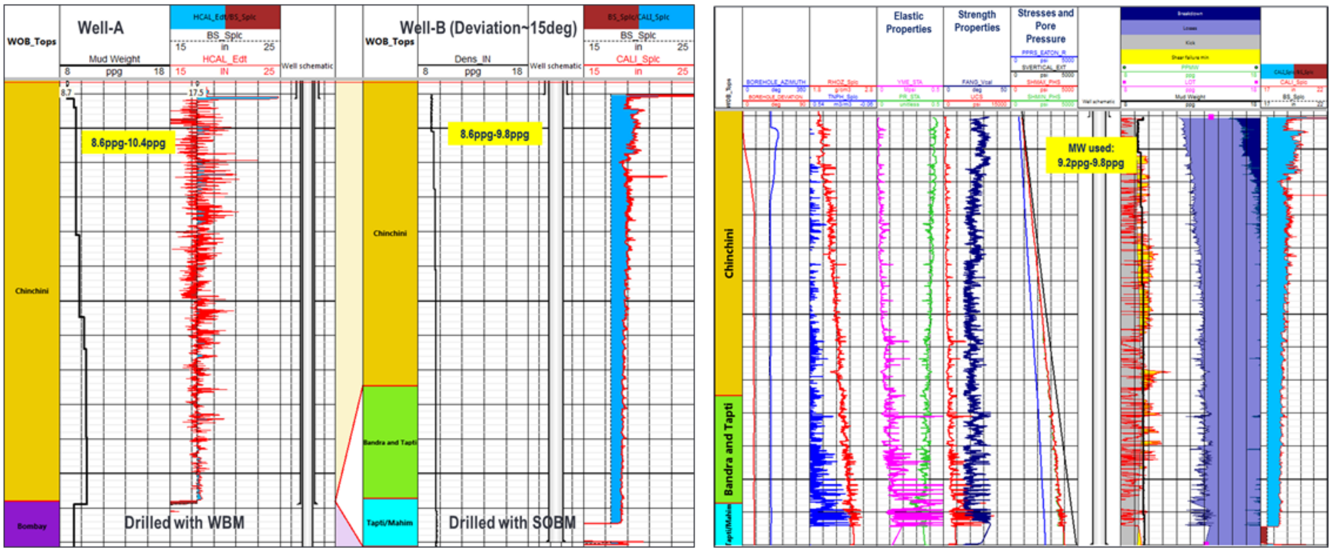
**Figure 3**: (a) Extended leak off test (XLOT) plot for well-A in Area-1 in Chinchini Formation. (b) Mud weight used and wireline caliper logs in well-A Area-1. Borehole is enlarged in both the wells in Chinchini Formation.

Area-5: 5 wells are analyzed in this area for PPFG modelling. In all the wells WBM has been used for drilling Chinchini Formation. Of these 5 wells, 2 wells (Well-B and E) have caliper and both are enlarged hole in Chinchini Formation as observed in other fields. Figure 6 shows the constructed MEM for Well-E. Mud Weight used is lower than shear failure gradient is in range of 9.4ppg to 9.8ppg. Caliper shows in gauge hole in the highlighted (green box) zone. Caliper data suggests reaction between clay and mud.

Properties of WBM and SOBM used in different areas are given in the Table 1.

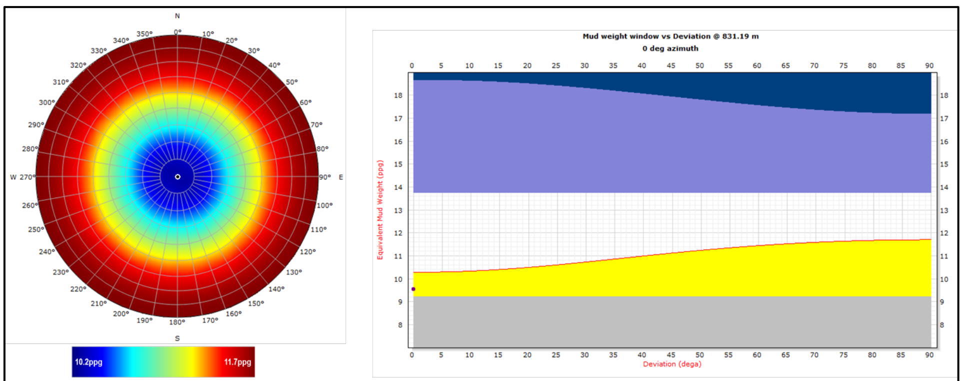
## Summary

- In all the areas, shales/clays of Chinchini Formation are isolated by putting a casing at the junction of first carbonate Formation.
- To drill this formation fast, mud weight is kept considerably low in the range of 9.0ppg to 9.5ppg.
- Borehole failure observed is influenced by mud type used (SOBM/WBM) and mud weight corresponding to shear failure gradient. Mud weight required to prevent hole collapse (shear failure) is in the range of 10.0ppg-11.0ppg. **Figure 7** compares the wells drilled with SOBM in three different areas.
- Borehole condition in all considered areas indicate that WBM is causing larger hole enlargement as compared to SOBM. It is most probably due to mud and clay reaction.
- Chinchini Formation in Area-1 (Shelf Margin Block) is thicker. It has high pore pressure increasing up to 11.4ppg and requires relatively higher mud weights. Near Shelf Margin, Chinchini Formation develops permeable reservoir facies which are also targets of exploration at the blocks of shelf margin areas. Sometime these permeable strata at shallower level poses significant shallow hazard risk for drilling, Rest of the areas pore pressure is hydrostatic to near hydrostatic (~8.4ppg-9.1ppg).
- Chinchini formation in Area 6 (Tapti Daman Block) located in the north side of Western offshore basin has in-gauged borehole and least drilling issues. Chinchini Formation characteristics in this area has behaved relatively different compared to areas 2 to 6.
- Future wells are recommended to drill with SOBM as it is less susceptible to reaction with clay/shales
- Multiwell plot with basic logs for representative well for all the areas is shown in **Figure 8.**
- Detailed clay typing of Chinchini Formation is being carried out to determine the best suitable mud properties for lesser Clay-Mud reaction.




(a) (b)

**Figure 4**: (a) Mud weight used and wireline caliper logs in well-A and well-B of Area-3. Borehole is enlarged in both the wells in Chinchini Formation. (b) MEM and wellbore stability analysis for well-B in Area-3




(a) Shear Failure Gradient Variation with Deviation and Azimuth

(a) Stable Mud Window Variation With Deviation

**Figure 5**: Shear failure gradient variation with deviation and azimuth and (b) Stable mud window variation with deviation for area-3

**Table 1 :** Mud properties for KCL-PHPA/Gel Polymer used in different areas

| S.No | Area | Well | Mud Weight (ppg) | VIS(sec) | Salinity (NACL-ppm | pH | PV/YP | Gel (0/10) | KCL(%) | FLT(degC) | WL(cc) | Solids(%) | Mud |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | A | 9.2-13.3 | 47-52 | 95700 | 9 | 21/23/27-32 | 8/11/2012 | 9-8 | 49 | 6.4-6.0 | 11 | KCL-PHPA |
| 2 | 2 | A | 9.0-9.8 | 43 | 64350 | 9 | 12/21 | 11/15 | 3 | 50-54 | 8 | 10 | KCL-PHPA |
| 3 | 5 | E | 9.4-9.8 | 44 | 49500 | 9 | 13/24 | 10/12 | 6 | - | 7.8 | 7 | KCL-PHPA |
| 4 | 6 | B | 9.4-9.6 | 42 | 27476 | 9 | 5/20 | 15-17 | - | - | 18-24 | 12 | Gel Polymer |

**Table 2 :** Mud properties of SOBM used in different areas

| S.No | Area | Well | Mud Weight (ppg) | VIS(sec) | Salinity (NACL-ppm | OWR | PV/YP | Gel (0/10) | ES(V) | FLT(degC) | WL(cc) | Solids(%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | A | 9.2-9.8 | 72 | 155842-155847 | 67/33 | 26/23-24 | 14/23-14/24 | 327/328 | 52 | 4.2 | 11 | SOBM |
| 2 | 4 | A | 9.3-9.8 | 71-80 | 157140-155790 | 63:35 | 36-37/20-25 | 14-15/19 | 310-405 | - | - | - | SOBM |
| 3 | 6 | A | 9.4-9.6 | 72 | 149581 | 62/38 | 34/23 | 12/18/20 | 329 | 54 | 5.6 | 10 | |

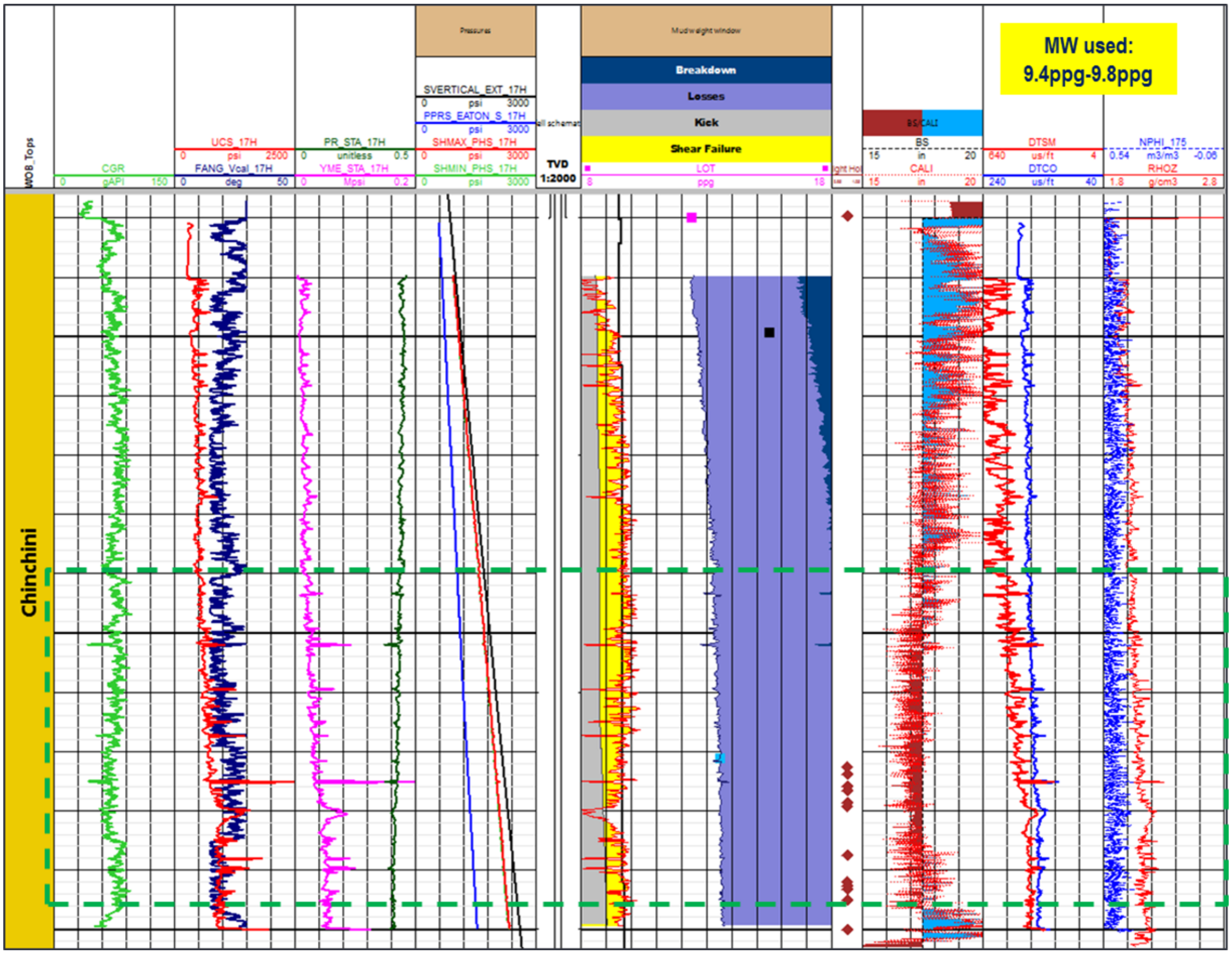



**Figure 6:** Mechanical Earth Model and wellbore stability analysis for well-E in Area-5

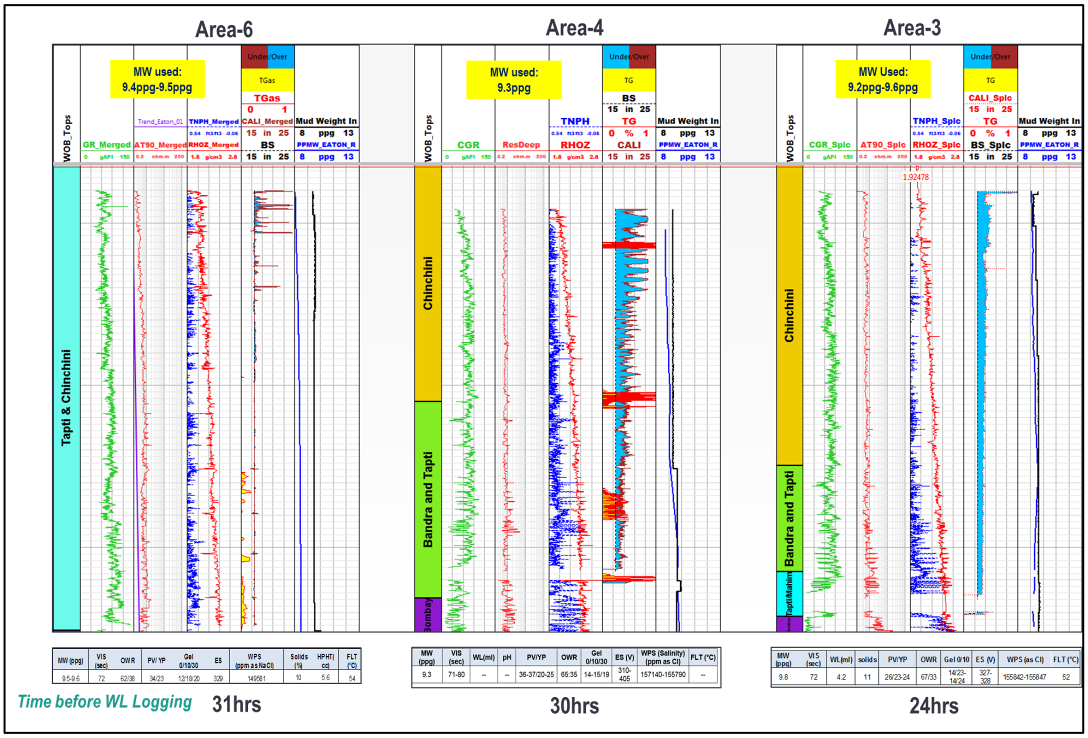



**Figure 7:** Well Drilled with SOBM in Chinchini

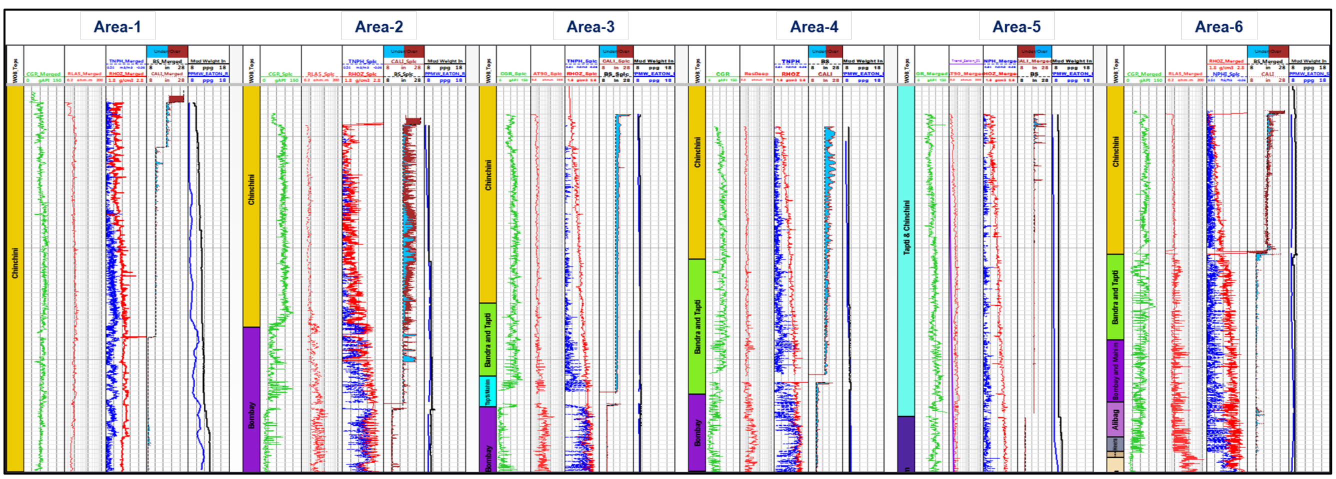



**Figure 8:** Multiwell plot for all the areas considered. track-1 shows the gamma ray(0-150GAPI), track-2 shows resistivity log (0.2-200ohm.m), track-3 shows density(1.8g/cc-2.8g/cc) and neutron porosity (0.58pu- -0.06pu), track-4 shows bit size and caliper (8in-28in) and track6 shows the pore pressure and mud weight (8ppg-18ppg).

## 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
3. Rajeev, Et.al., 2016, Reducing Drilling Risks in ERD Wells Through Geomechanical Solutions, SPE 181399