Comprehensive Post Drill Wellbore Stability Analysis with 1D-Mechanical Earth Modelling- A case study from Pallivaramangalam field - Cauvery basin

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Abstract

Well Bore Stability Analysis (WBSA) computed through 1D Mechanical Earth Modelling (MEM) is an effective way to mitigate drilling complications. Profound knowledge about local stress directions, formation pressure and rock strength can proactively geo-steer the well trajectory into a safe and stable direction. 1D MEM propounds an efficient, accurate and convenient methodology for the selection of drilling mechanism like Managed Pressure Drilling (MPD), drilling with high yield stress mud[8] etc. This paper assesses the well bore stability challenges met during the drilling of recent Well-A in Pallivaramangalam field of Cauvery Basin. A comprehensive study of the well is made by collecting information from different sources like: well logs, drilling events, reservoir study, testing results, core measurements, offset well logs and other geological information.1D-MEM is made by encapsulating all these information and analyse the elastic properties, rock strength, pore pressure and in-situ stress magnitudes etc. Thorough understanding of each drilling events bolsters the integrity of proposed model. WBSA explicates breathing/ballooning effects of the formations encountered during the drilling of the interval 2638 m – 2943 m. It also explains the concomitant well bore activities such as reduction of mud weight and ballooning effect confronted during drilling of the interval 2943m - 3215 m. The post drilling analysis of the well with the 1D MEM recommends a safe mud window and casing policy for the future drilling wells in this study area.

Introduction

Optimization of non-productive time (NPT) during drilling is one of the major parameter for designing a well. Several well bore stability challenges leads to stuck ups, heavy mud loss, formation break outs, kicks etc. An exhaustive geomechanical study of the well and field can help to minimise these problems and can reduce the NPT and cost of the well construction. The present well-A is placed in Pallivaramangalam area which is located on the south-western plunge of the Karaikal High in Nagapattinam Sub Basin of Cauvery Basin. Structurally, the area is characterized by almost west-east trending Karaikal High and part of the adjoining Tranquebar depression. Dominant faults are observed parallel to the major structural alignments.During the drilling of 8½" hole section in this well, multiple stuck ups, balloning effects and reduction of mud weight due to excessive trip gas were confronted. Different controlling mechanisms were used to solve these challenges. Initially the well was planned to complete by drilling 8½" hole with 5½"casing but the complecations during the drilling of 8½" section leads to modifiy the drilling plan further. Based on the new plan, 8½" hole section was placed with 7" casing and continued further drilling to the target depth by 6" hole and completed the well in 5" casing. Finaly 53 additional days were utilized to complete the well by deviating/modifying from the actual plan such as: drilling 6 hole, placing 7" & 5” casing, placing cement at open hole and placing LCM etc. 1D-MEM of the well is prepared by using all the field/well information and log data. This 1D-MEM model is verified by calibration data like LOT, lab measurements of core data and production data. The validated model recommends a way forward for avoiding NPT while drilling future wells in this region.

Brief history of drilling events and complications during 8½" section

Well-A was drilled to the depth 3328.5 m in five phases and details are shown in Table-1. The 8½" hole was drilled vertically from 2638 m to 2943 m without any drilling complications by using mud weight in the range of 1.3 – 1.39 g/cc. But the drill string was stuck at 2708 m while pulling out for bit change after drilling down 2943m. String was released from stuck point after several attempts. During running down the new 8½" bit with the circulation of mud 1.42 g/cc, 40m^3 of mud was lost into formation and return of 20m^3 of mud was observed when the circulation stopped. Dynamic loss of 13 m^3 mud was observed during circulation and 13 m^3 was returned after stopping the circulation. Several steps were followed in multiple times to control these series of loss and return of mud (Ballooning effect)[4,5] viz, placing $CaCO_3$ pill, cementing at open hole section at different depths (5 times), and dynamically squeezing with Light Compactable Mud (LCM) etc. 8½" hole was further drilled from 2943 m to 3215 m by using mud weight of 1.42 to1.5 g/cc and observed reduction of mud weight from 1.5 g/cc to 1.24 g/cc with the presence of trip gas in rage of 9.7 % to 67 % at various stages of drilling. Simultaneous problems of ballooning effect and reduction of mud weight by the trip gas caused the drilling a very strenuous job. Drilling of 8½" hole was stopped at 3215 m and 7” liner was lowered in this section by modifying the initial well plan. Well was further drilled to bottom by 6”hole and completed by placing 5" casing.

Bit Size (in)	Casing Size (in)	Drilled Depth (m)	Casing Shoe (m)	Planned/Actual Days
26	20	205	200	5/5
17½	13⅜	1402	1398	24/25
12¼	9 ⅝	2641	2638	59/50
8½	7 Liner (planned 5½"casing)	3217	3214	85/116
6	5	3328.5	3326	138 days (Well planned to complete in 8½ hole with 5½"casing).

Table-1: Drilling completion details of the well

Borehole ballooning or breathing effect

Breathing/Ballooning effect is the phenomenon of reversible drilling fluid losses and gains during drilling. It is generally observed in the formations having natural micro fractures/micro-fissures and drilling induced fractures[5]. There are three main mechanisms caused for this ballooning effect: 1. Elastic deformation of the borehole walls 2. Variation in temperature of the drilling fluid 3. Opening/Closing of natural fractures and drilling induced fractures present in the borehole wall[5]. The magnitude of loss and gain of mud by first two mechanisms are considerably small. Therefore, fracture opening and closing may be the key parameters that affect formation ballooning effect[5, 6, 7]. During circulation, the effective circulation density (ECD) of mud is near or exceeds the formation fracture opening pressure and hence the mud flows into fractures. But after stopping the circulation, the ECD falls below the fracture opening pressure. It caused the closure of factures and hence the return of mud into the bore hole. Misinterpreting the ballooning phenomenon as a well kick can lead to the application of standard well control methods. It can further aggravate the problem and may leads to severe implications even to the extent of well failing to meet its objective or abandoning of well etc.

Methodology

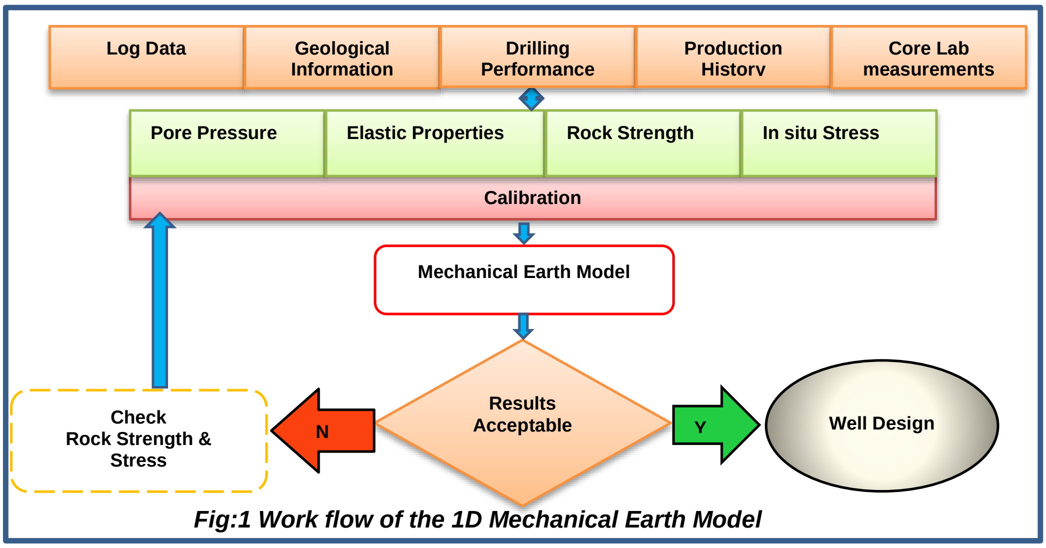

Fig:1 Work flow of the 1D Mechanical Earth Model

An integrated work flow of the 1D-MEM is shown in Fig 1. Basic petrophysical evaluation is carried out by using the acquired logs and other geological information. Natural fractures and other drilling events (breakouts and Drilling induced fractures-DIFs) are identified by using Resistivity Image logs. Overburden stress is calculated by extrapolating the density log to surface (Fig-2) and unloading effect is determined with Hoesni plot (Fig-3) at deeper sedimentary section. Pore pressure is calculated using Eaton's method and calibrates with the reservoir build up pressure. Fracture gradient (FG) is calculated from pore pressure (PP) and overburden gradient. Shear and compressional data are used to calculate Dynamic moduli. Static young's modulus is derived from dynamic young's modulus by *John Fuller method*. These static values are in the range of the static lab measurements derived from the core extracted from the offset well at the correlated depth. Different rock strength parameters such as Unconfined Compressive Strength (UCS), Friction Angle, and Tensile Strength are calculated to understand the ability of the rock to withstand the in-situ stress environment around the well bore. Poro-Elastic Horizontal Strain Model is used for horizontal stresses calculation. The minimum horizontal stress is calibrated with LOT values. Wellbore stability analysis (WBSA) has been carried out by preparing 1D MEM of the well.

Analysis and discussions

Prominent conductive micro natural fractures and bed boundaries are observed in Resistivity Image log in the interval 2665 m to 2755 m, 2780 m to 2925 m (Fig 5). Fracture analysis by the stoneley reflections also corroborates the presence of open fractures in this section. Presences of drilling induced fractures (DIFs) are shown at various places in the interval 2680 m to 2735 m and 2795 m to 2863 m (Fig 5). Natural fractures/micro fissures observed in the interval 2665 m – 2755 m and 2780 m – 2925 m may be instigating the ballooning/breathing effect. Hoesni plot shows that the deeper cretaceous formation follows normal compaction trend and neglecting the presence of unloading effect. Two different trend lines are observed for Tertiary and Cretaceous depositions (Fig-3). These results are in coherence with the CEWELL report[1]. Pore pressure abnormality is observed in the intervals 2909 m - 2918 m and 3131 m -3225 m (Fig 4). The deviation from the normal hydrostatic pressure shows that these two intervals are comparatively at high pressure zone as shown in Fig -4. Calculated SHmax and Shmin horizontal stress by Poro-Elastic Horizontal Strain Model reveals that among computed stresses, Shmin is the least in magnitude and Vertical stress is the most (Fig 4). It shows that the area of this well is predominantly in a normal faulting regime. The direction of SHmax is determined from the DIFs and is observed in NNW-SSE direction (Fig 5).

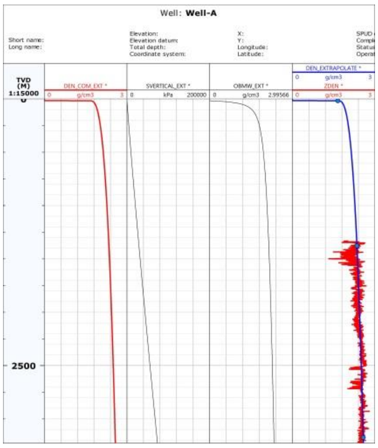

Fig:2 Overburden Stress Calculation

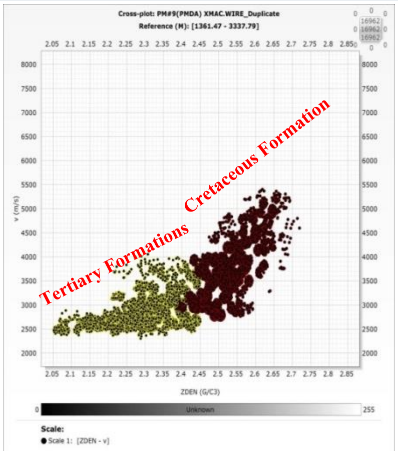

Fig: 3 Hoesni Plot

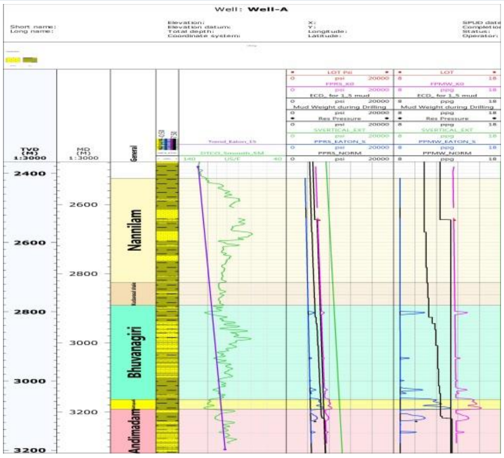

Fig: 4 : Pore pressure calculated with Eaton Method

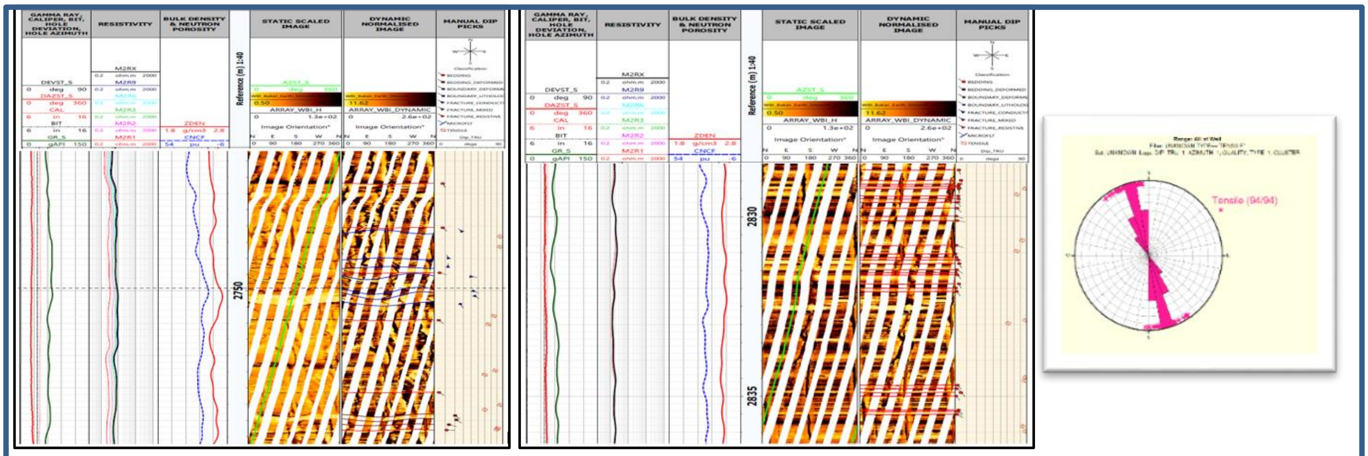

Fig-5 shows presence of natural fractures and Drilling induced fractures in Resistivity Image Log. SHmax direction shows as NNW-SSE dir.

Based on the drilling complications encountered during the drilling of 8 ½” hole, the discussion stated below are divided into two sections. First section covers the interval 2639 m to 2943 m (zone-1) where the ballooning effect occurred and the second section covers the interval 2943 m to 3215 m (zone-2) where ballooning effect as well as reduction of mud weight occurred. Different ECD curves used at different times of drilling are shown in the Fig-8 such as 1. mud weight while drilling, 2. while running in after the first stuck up (ECD during RIN) and 3. during final phase of drilling (ECD for 1.5 mud).

Zone-1: Interval 2639 – 2943 m

First phase of 8½" hole section (Zone-1) was drilled smoothly by using the mud density in the range of 1.32 – 1.39 g/cc. Well bore stability analysis (WBSA) depicts that the mud loss window (light blue shade area) in the mud weight window track in the Fig-8 is hardly touching the curve-**mud weight while drilling.** It shows the fracture gradient is above the ECD and hence no mud loss. Mud density was further increased to 1.42 g/cc while running in the drill pipe after clearing the first stuck up. Mud loss was observed while circulation and return of mud while stopping the mud pump. WBSA also shows that the mud loss window cross the curve- ***ECD during RIN*** (red curve in mud weight window track) at various places which means that the ECD crosses the Fracture Propagation Pressure (FPP) and mud loss started to occur. When the mud pumps were stopped, the ECD value falls below the Fracture Opening Pressure (FOP) causing the closure of fracture and subsequently discharge of mud into the bore hole. Mud weight was further increased to 1.5 g/cc where the mud loss window crosses the ***ECD for 1.5 mud*** curve (black curve*)* at more places as shown in Fig-8 causing severe Ballooning effect. Resistivity image log (Fig: 5) shows many drilling induced tensile fractures against these places. Cement plug and high viscous materials were placed in open hole to control this ballooning effect. These materials closes the fractures and giving an interim alleviation to the problem.

Zone-2: Interval 2943- 3215m

Second phase of 8½" hole section (Zone-2) was drilled with the mud density in the range of 1.42 -1.5 g/cc. Presence of trip gas in the range of 9.7 % to 67 % and reduction in mud weight from 1.5 g/cc to 1.24 g/cc were reported in this interval. Pore pressure computation delineates comparatively high pressure zones at the bottom of Bhuvanagiri, Sattapadi and top of Andimadam formation in the interval 3131m - 3225 m shown in Fig-4. WBSA enunciated that the mud hydrostatic pressure in bore hole is below the pore pressure against certain places in this interval (mud weight window track in Fig:8). Based on petrophysical analysis and geological input, two hydrocarbon bearing zones are identified in Bhuvanagiri and Andimadam formations near to this high pressure zones. Shear failure/break out is predicted in 1DMEM which is validated by caliper logs against this interval.

1DMEM analysis delineates that the pore pressure is marginally above the mud hydrostatic pressure near the hydrocarbon zones which caused the presence of trip gas in the mud. However, the effective circulation density was above the pore pressure (***ECD for 1.5 mud*** in Fig: 8) and it effectively maintained to avoid any untoward formation kicks during drilling. At the same time the ECD values were above the FPP causing the ballooning effect at **Zone-1**. Simultaneous problems of ballooning effect and reduction of mud weight were reported during the drilling of **Zone-2.** 1D MEM give a safe mud window and casing policy for mitigating these problems while drilling future wells in this area. Based on the analysis, it is concluded that the interval 2638 - 3150 m in this well should have been drilled with a safe mud window of 1.24 to 1.28 g/cc and completed with casing before further drilling down. The interval 3150- 3290 m should have been drilled with safe mud window of 1.51 to 1.57 g/cc (as shown in Fig:6&7).

Elastic properties calculated in Andimadam formation shows that static young's modulus is in the range of 0.36 – 1.9 M psi, static Poisson's ratio in the range of 0.138 – 0.32 & UCS in the range of 3500 – 6600 psi and these values are almost in match with CEWELL report[1].In the Nannilam formation against the sand -14 developed in the interval 2678 m – 2703 m, the static young's modulus is in the range of 1.34 – 3.8 M psi, static Poisson's ratio in the range of 0.06 – 0.27 & UCS in the range of 5300 – 7200 psi.

Conclusions

Systematic integration of various data from different sources leads to develop an IDMEM of the Well-A. Well bore stability problems confronted during the drilling of 8½" section is effectively analysed in this paper. Mud weight and ECD values of the well plays a major role in well complications. When the ECD crossed the FPP of the natural conductive fractures/DIFs developed in the Nannilam and Bhuvanagiri formation caused the mud loss during circulation. When the mud pumps were stopped, the ECD value reached to back to the actual mud weight causing the closure of fracture and subsequently discharge of mud to the bore hole. A comparatively high pressure zone was encountered at the lower part of Bhuvanagiri, Sattapadi and top of Andimadam formation. The low mud weight below the pore pressure allowed the formation fluid to flow into well bore causing the presence of 9.7% to 67 % trip gas and subsequent reduction of mud weight from 1.5 to 1.24 g/cc. But the ECD in the Zone-2 while drilling was above the FPP of the Zone-1 and it caused ballooning effect at Zone-1. Hence ballooning effect and reduction of mud weight were encountered during the drilling of Zone-2. This study concluded that the interval 2638 m - 3150 m should have been drilled with a safe mud window of 1.24 to 1.28

g/cc and completed with casing before further drilling down. The below section from 3150- 3290 m should have been drilled with safe mud window of 1.51 to 1.57 g/cc. **Considering this results, the new proposed well near this location is planned to drill with above mentioned safe mud window and casing policy**

Acknowledgement

We express our sincere gratitude to ED-Asset Manager-Cauvery Asset and CGM (W) - HLS Cauvery Asset for their encouragement and valuable guidance. The technical support and knowledge inputs provided by Drilling services and Subsurface department are thankfully noted. Authors wish to thank management of Oil and Natural Gas Corporation Ltd. for the permission to publish this paper. Views expressed in the paper are those of authors only.

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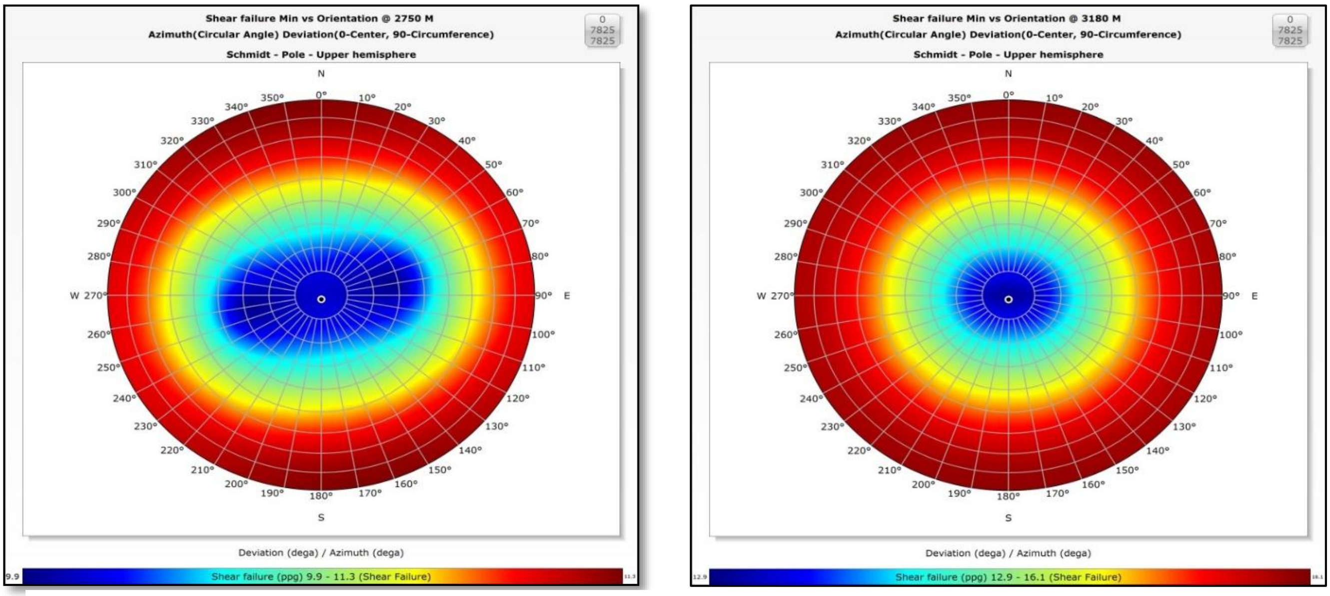

Fig: 6 Borehole stability as a function of mud weight and well profiles at depth 2750 m & 3180 m

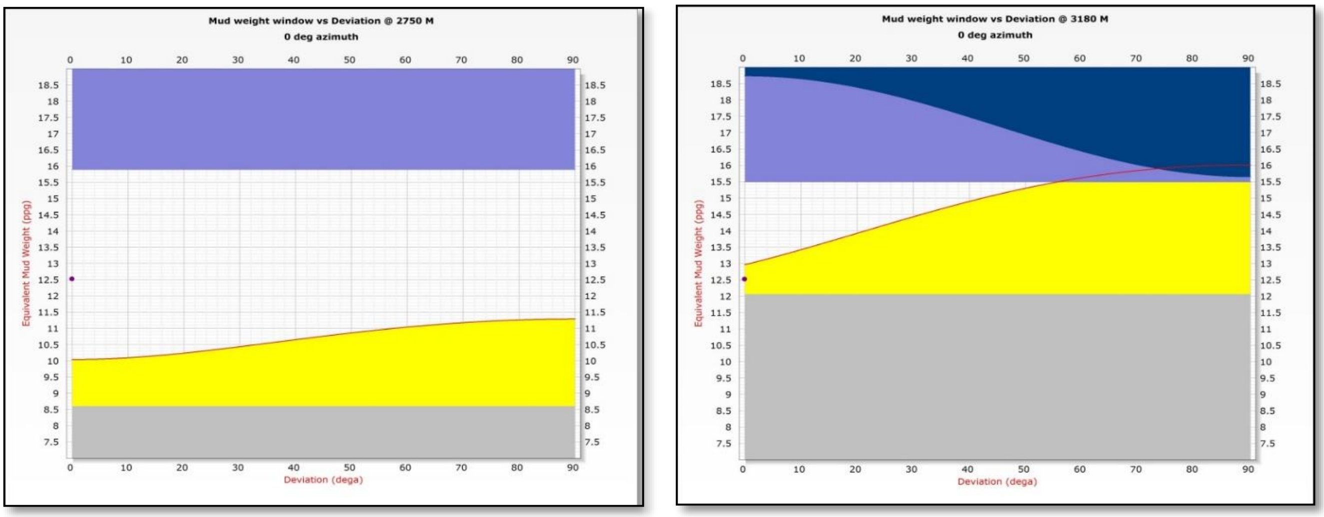

Fig: 7 Mud weight Vs Deviation at depth 2750 m & 3180 m

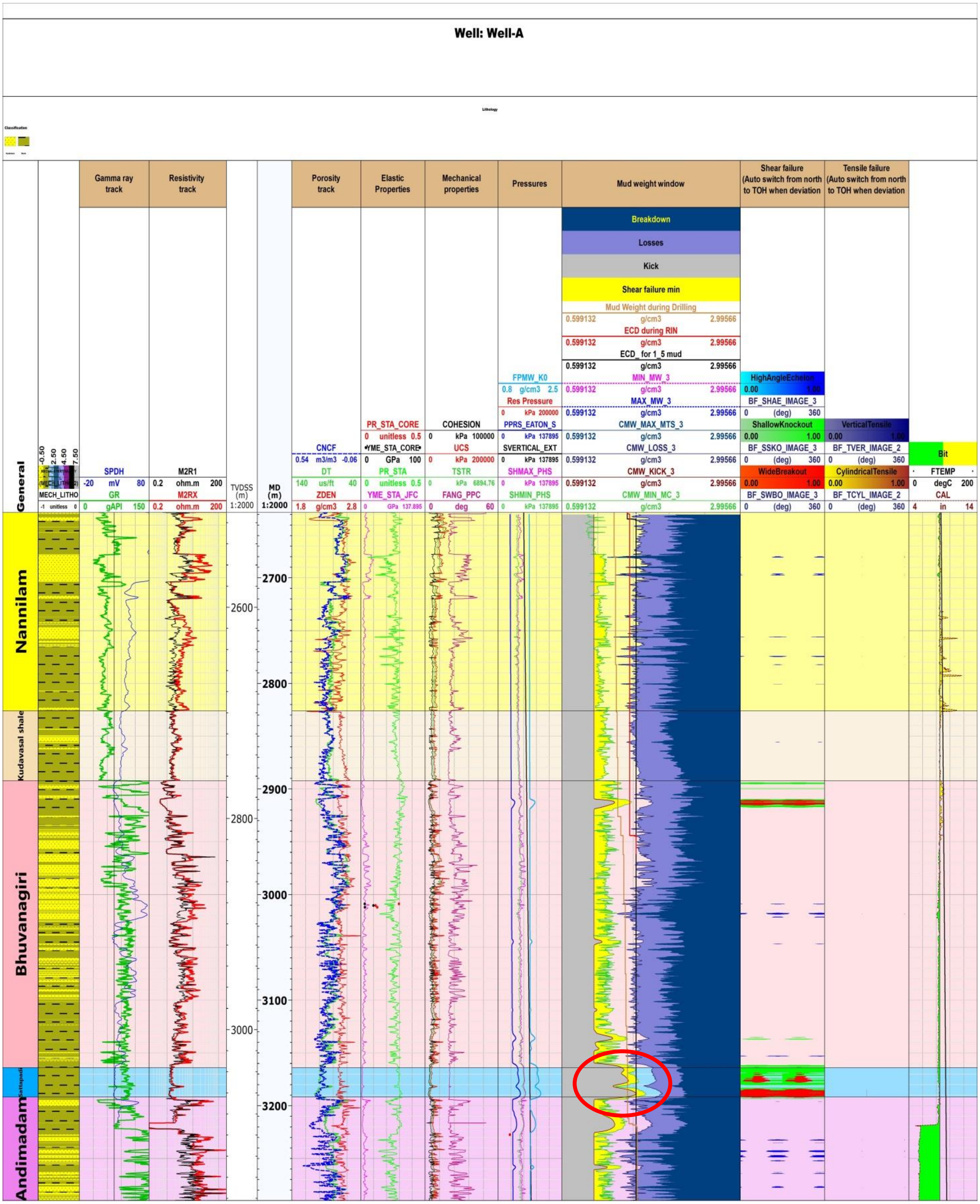

Fig:8: ID-MEM of Well-A in the interval 2639 – 3290 m