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[EA]Geomechanics Wellbore Stability Analysis in Successful Drilling of a Challenging HPHT Exploration Well in North Sumatra*

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Abstract

One of the Pertamina exploration wells in North Sumatra targeted an unconventional shale gas reservoir, the Lower-Baong Formation. Based on existing wells data, this formation is High Pressure and High Temperature (HPHT). The pore pressure was indicated as up to 2.2 g/cm3 (18 ppg) and the temperature is more than 350°F. A kick event was documented at one of the offset wells during drilling in 2004. A risk of kick and possible narrow mud weight window are predicted for this upcoming exploration well.

To achieve the drilling target, the pre-drill geomechanics model which provides pore pressure, breakout, fracture gradient and breakdown mud weight analysis was conducted. Since narrow mud weight is suspected, accuracy of the pre-drill geomechanics model is of paramount importance to minimize the drilling risk and enable accurate planning and mitigation.

This study is located in Alpha Field in north Sumatera province (Figure 1). Several wells had been drilled near to this field with several reservoir targets. At the time the study was conducted, one exploration well BCL01 was planned which targeted the Belumai carbonate reservoir, with the Lower Baong for unconventional shale gas as the secondary target. Stratigraphically based on Bahesti et al. (2013), the planned well BCL-01 will encounter shallower Keutapang – Seurula, a dominantly sand formation, then followed by the Baong Shale Formation and carbonate Belumai Formation at the bottom part (Figure 2).

Drilling Event Review - Offset Wells

The purpose of the drilling event review is to gather information that will be used to identify and characterize the drilling problems experienced in the field. These drilling problems were highlighted and will be considered as the focus area in the geomechanics study.

The most representative offset well was selected and used in this geomechanics analysis. Well-A is located 9.8 km away to the northeast from the planned well BCL-01 (Figure 2). This well started drilling on December 2003 and reached TD after six months of drilling, on July 2004 (Figure 3). The longer period of drilling indicates that many issues occurred during drilling. This well was side tracked twice due to stuck pipe. During drilling the Lower Baong Formation experienced a kick event when using 2.0 SG (16.7 ppg) mud weight. Right after the kick, the mud weight was increased to 2.2 SG to overcome the kick, but then some losses start to be observed. This event was indicating the narrow mud weight window. Afterwards, the well successfully reached TD.

Mechanical Earth Model Construction

The method and workflow to construct mechanical earth model for the offset well (Well-A) and then to propagate it to the planned well (BCL-01) is illustrated on Figure 4. Development of a Mechanical Earth Model (MEM) (Plumb et al., 2000) is essential in making the best use of field geomechanics information. The MEM is a description of strengths, stresses and pressures as a function of depth, referenced to a stratigraphic column. Resulting MEM consisted of, amongst other data, continuous profiles of the following rock mechanics information and parameters:

- A description of rock fabric (i.e. the mechanical stratigraphy of the formations considered);
- Rock elastic parameters: including Young's modulus and Poisson's ratio;
- Rock strength parameters: Unconfined compressive strength (UCS), tensile strength and angle of internal friction; and
- Stress model: Vertical stress, minimum and maximum horizontal stress magnitudes and orientations, and pore pressure.

Once a MEM is constructed, it can be used to estimate and predict the best possible methods for safely drilling and completing both a single borehole and for field development.

Wellbore Stability Analysis - Rock Failure Criteria – Offset Well

Mohr Coulomb was used as failure criteria to determine shear failure and Maximum Tensile Stress criteria to determine tensile failure. The results of wellbore stability analysis for offset well Well-A is shown in Figure 5 track 13. The narrow mud weight window is predicted at the Lower Baong Formation which is consistent with what was observed from the drilling records, where the losses occurred when the mud weight was increased rapidly from 2.0 SG to 2.22 SG. And the pore pressure calculated after drilling is 2.2 SG. Therefore, less than 0.22 SG different between pore pressure and fracture gradient.

Pre-Drill Wellbore Stability Analysis of the Planned Well BCL-01

In order to conduct pre-drill wellbore stability analysis for planned well BCL-01 and come up with recommended mud weight and casing setting depth to drill safely, the validated Mechanical Earth Model (MEM) results that have been constructed in the offset well Well-A are propagated to the planned well BCL-01. This propagation method is respecting the well trajectory, well distance and formation top correlation (Figure 6).

Respecting that the stress and strain cannot be propagated, the wellbore stability (WBS) analysis needed to be conducted independently for the planned well based on the propagated MEM's data. The method and parameter in conducting WBS in this planned well BCL-01 were taken directly from the offset well Well-A. The main objectives of the WBS analysis at the planned well BCL-01 was to give the recommendation of a safe and stable mud weight window, especially in the over pressured Lower Baong Formation. Besides that, the casing design and potential drilling hazards mapping can also refer to pre-drill WBS analysis.

Results - Mud Weight Window BCL-01

From the pre-drill WBS analysis of the planned well BCL-01, the over pressured zone at Lower Baong Formation indicating the estimation of 2.3 SG pore pressure. The higher pore pressure in this planned well BCL-01 compared with 2.2 SG pore pressure in the same formation in offset well Well-A is due to shallower true vertical depth (TVD) (Figure 7).

Based on the pre-drill geomechanics results, casing design had been revised to minimize the risk and for safety of drilling. Higher pore pressure estimation at the Lower Baong Formation was anticipated by increasing mud weight recommendation to maximum 2.3 SG and also switched to a Managed Pressure Drilling (MPD) system. The casing point also revised by adding another section to isolate the over pressured zone, from above and below sections. Realtime geomechanics monitoring focused on the over pressured zone was then necessary to perform.

Accurate pre-drill geomechanics analysis impacts the drilling operation efficiency and safely drilling into reservoir targets. As analyzed in this study, the planned well mud weight window is extremely narrow and needs high accuracy of the geomechanics analysis to recognize drilling risk and address the correct solutions. The results of pre-drill geomechanics analysis in this BCL-01 has successfully guided the drilling operation on target and without significant problem.

Validation - Post-Drill Analysis of Well BCL-01

Once the BCL-01 drilling was completed, the post-drill analysis was performed to update and verify the method and parameter of pre-drill analysis. The actual logging data and drilling events were used and analyzed using the same workflow with the pre-drill geomechanics analysis.

Drilling Event Review BCL-01

Figure 8 shows the time versus depth plot of drilling events in well BCL-01. Below is a summary of the events that can be used to validate pre-drill 1D MEM:

• The minimum horizontal stress (σh) magnitude was validated against five LOT tests.
• Trip gas and connection gas were used as a guide for pore pressure estimation using logs data.
• Partial losses in non-fractured formation are used as a guide for minimum horizontal stress (σh) magnitude estimation.

Wellbore Stability Analysis of BCL-01

The actual well bore stability analysis is shown in Figure 9 and indicates consistency against prediction from the pre-drill geomechanics model. In terms of pore pressure, the pre-drill maximum pore pressure estimation was 2.3 SG, and then the actual maximum pore pressure is 2.27 SG, thus the difference of estimated and actual of pore pressure at over pressured zone Lower Baong Formation is only 0.03 SG (0.25 ppg).

Based on actual wellbore stability results, because of the recommended mud weight used during drilling, there is no indication of shear failure or borehole breakout events in well BCL01, although there was an extremely narrow mud weight window. Based on drilling records and calculation, the pore pressure identified is a maximum 2.27 SG and the fracture gradient is 2.33 SG. Therefore, only 0.06 SG (0.5 ppg) was the available safe window.

Conclusions

The following summary and recommendations have been drawn based on the 1-D Mechanical Earth Model construction and Wellbore Stability (WBS) analysis:

• Geomechanics Analysis (MEM and WBS) was performed in the offset well Well-A, and then propagated to the planned well BCL-01 to give the recommendation of the safe and stable mud weight window, especially in the over pressured Lower Baong Formation.
• Pore pressure is calculated using Eaton's method based on sonic log data and is validated against calculated pore pressure (Well-A) and trip gas and connection gas (BCL-01).
• Minimum horizontal stress is validated against MOTs (Well-A) and LOTs (BCL-01).
• Stress regime at the well location was interpreted as a dominantly normal stress regime.
• Maximum horizontal stress direction in well BCL-01 was taken from the sonic scanner advance processing, showing a N128^{o}E orientation.
• Post-drill geomechanics analysis was also performed in the BCL-01, to validate the pre-drill model parameter and MEM construction methods.
• Post-drill results show that the prediction during pre-drill is quite accurate. The difference of predicted and actual pore pressure at over pressured zone Lower Baong Formation is only 0.03 SG.

• By having accurate pre-drill geomechanics analysis, the well was successfully drilled safely to the formation target without a significant drilling problem, although the mud weight window is extremely narrow.

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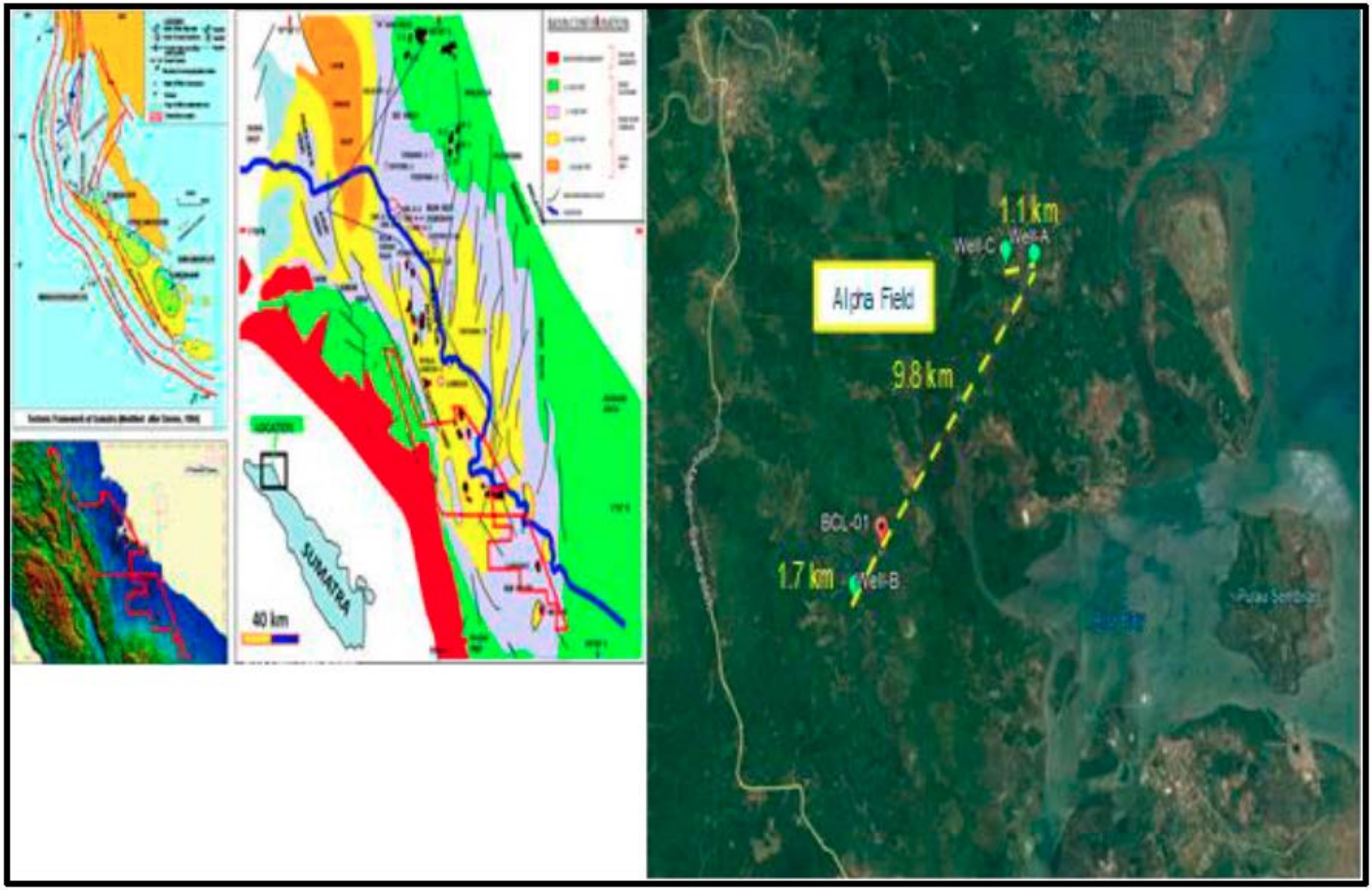

Figure 1. Alpha Field location in the North Sumatra province of Indonesia (after Bahesti et al., 2013).

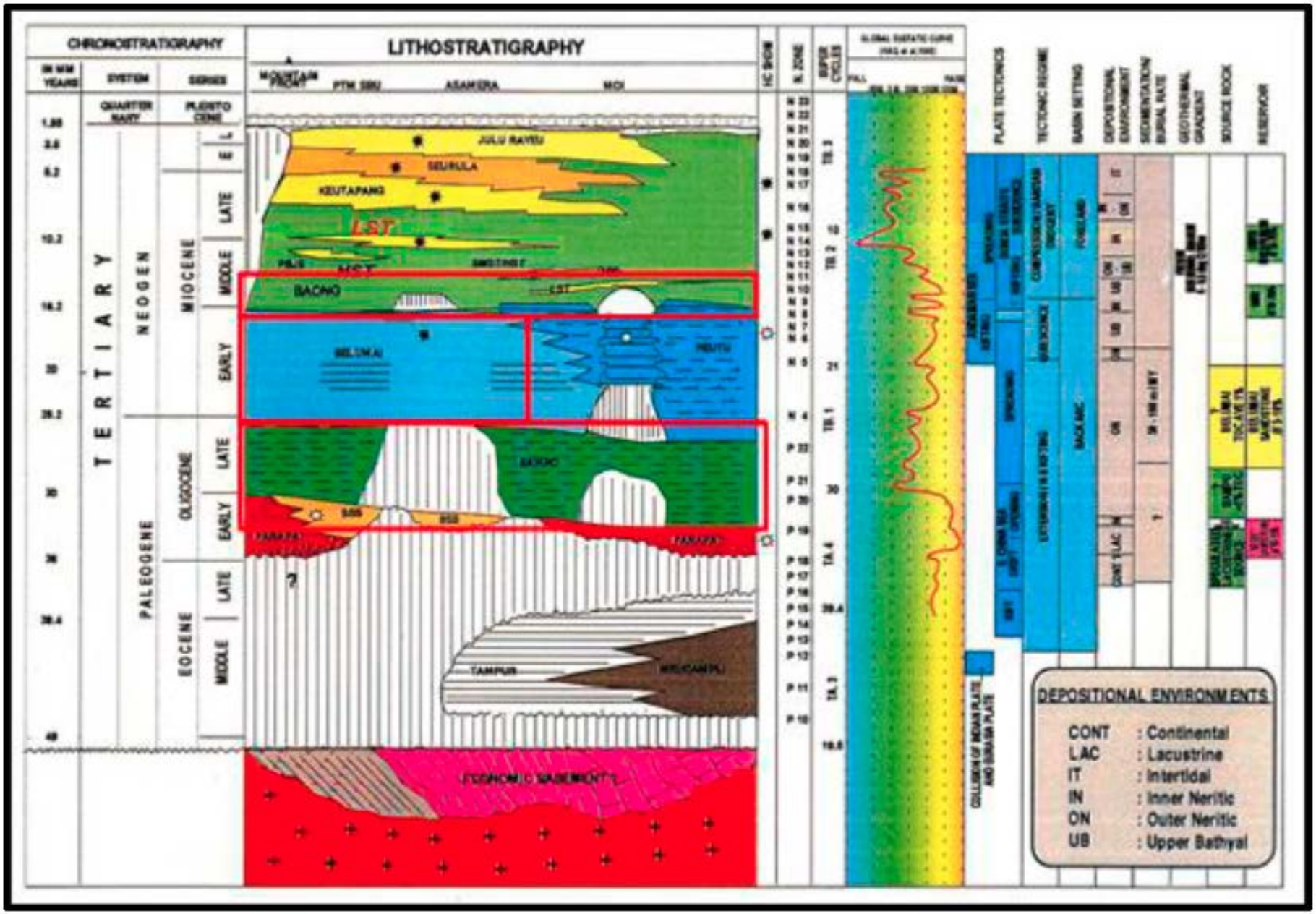

Figure 2. Regional stratigraphy in the Alpha area (Bahesti et al., 2013). Baong Shale and Belumai carbonate are the main targets in planned well BCL-01.

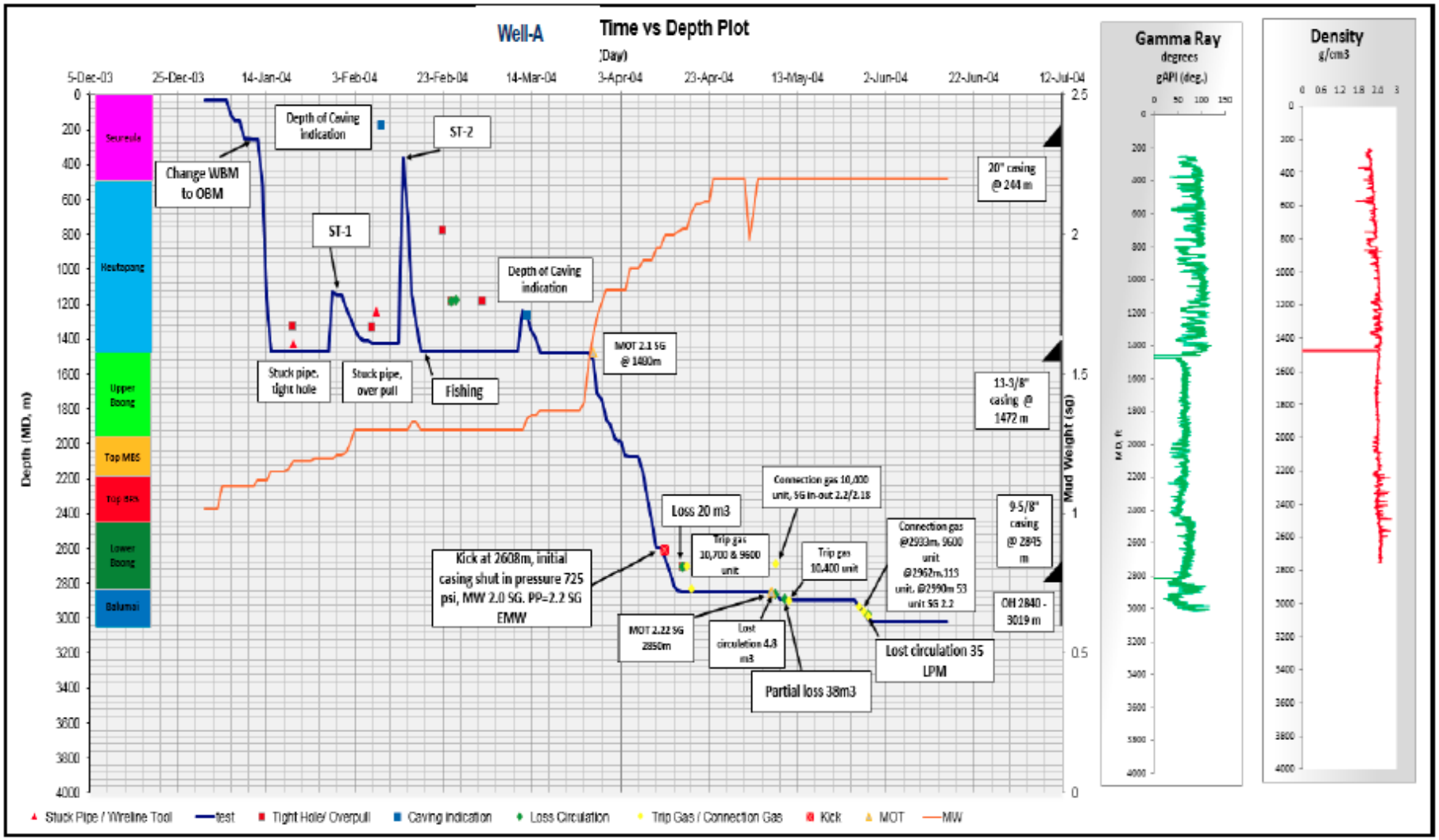

Figure 3. Time vs. Depth Plot of Offset well, Well-A.

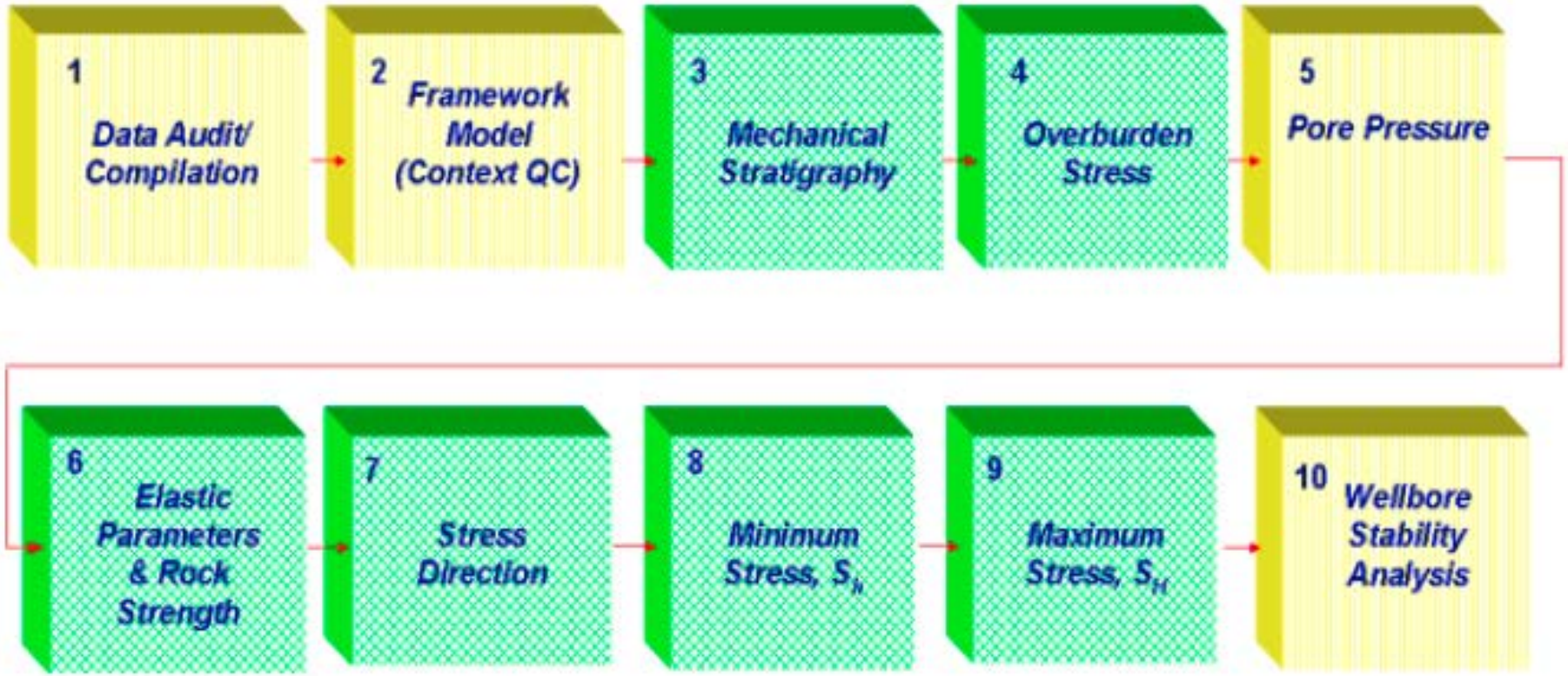

Figure 4. A typical workflow for Mechanical Earth Model (MEM) construction.

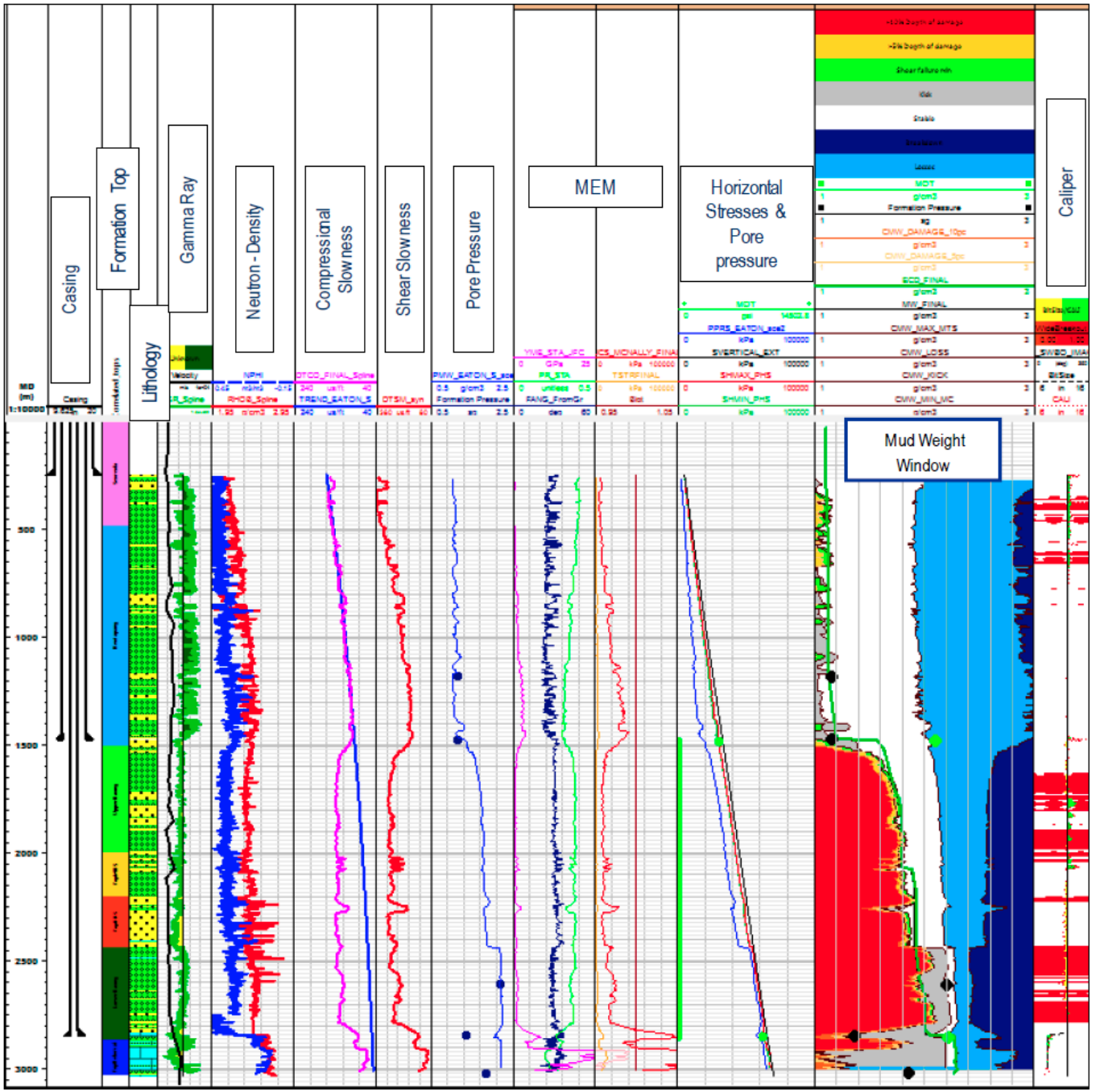

Figure 5. Offset well, Well-A Wellbore Stability (WBS) analysis and mud weight window.

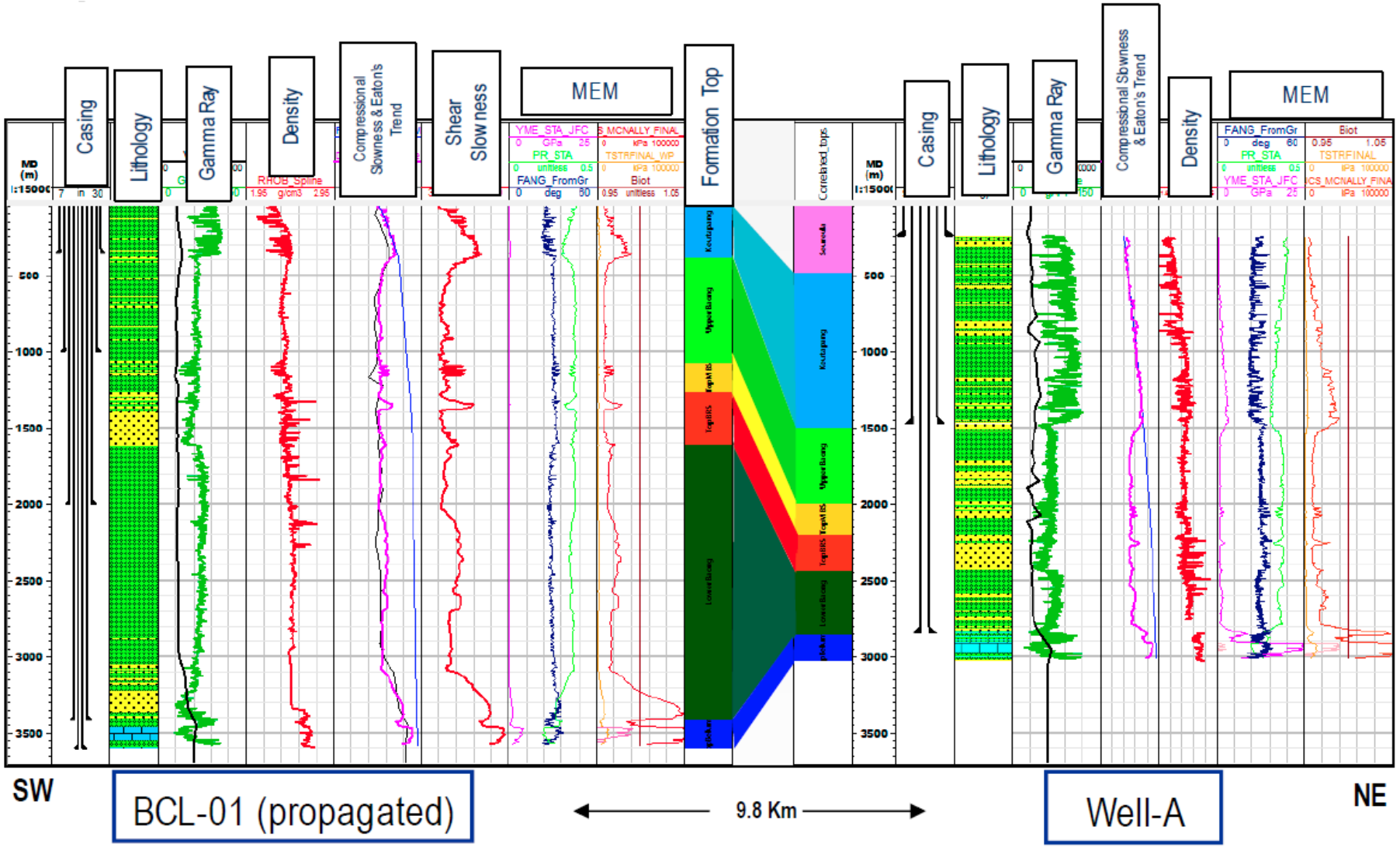

Figure 6. Mechanical Earth Model's (MEM's) log propagation from offset well Well-A to the planned well BCL-01. Lower Baong Formation (dark green) in the BCL-01 is shallower than Well-A and has more formation thickness.

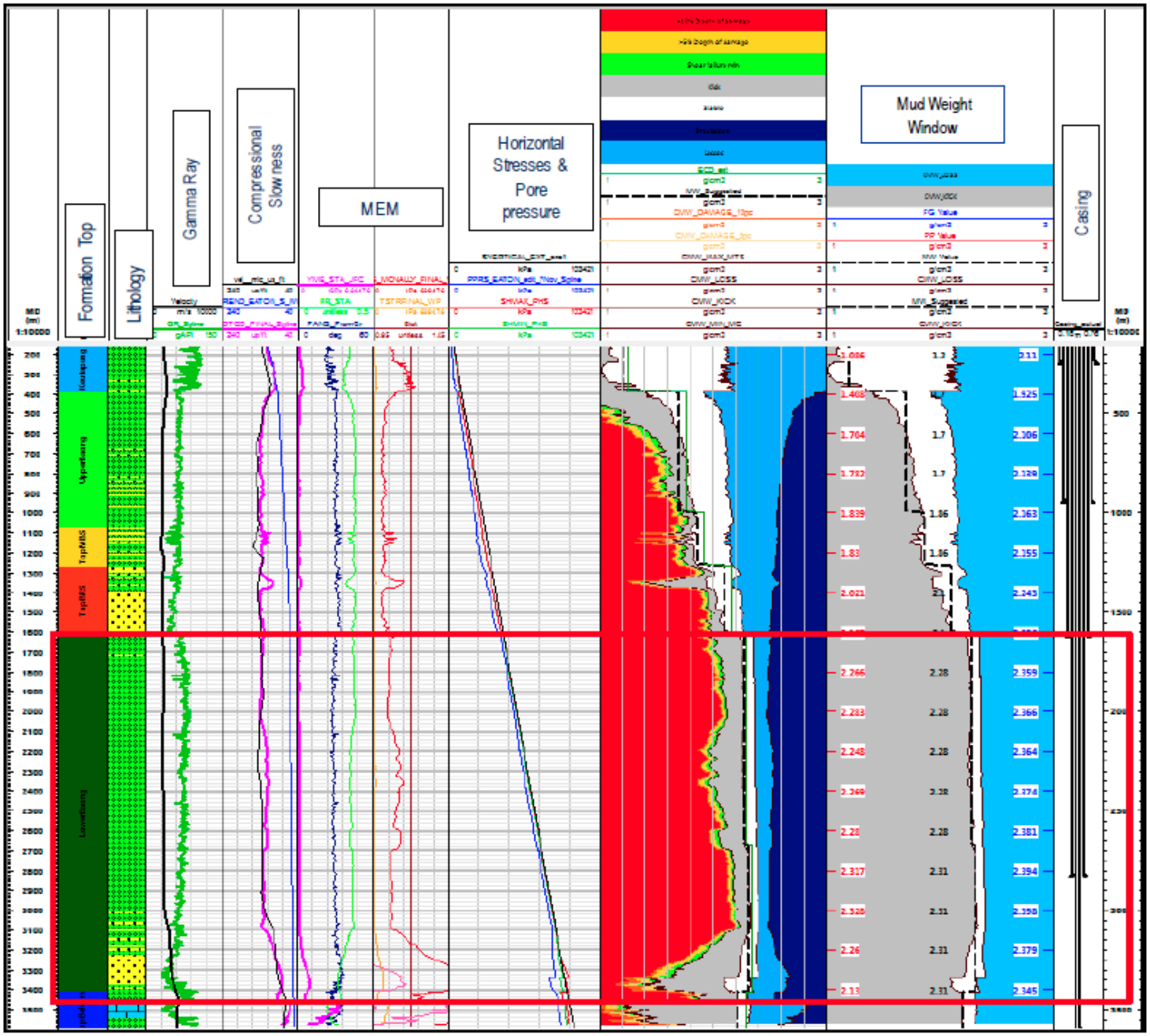

Figure 7. Pre-drill Wellbore Stability (WBS) Analysis of planned well BCL-01. Lower Baong Formation (red box) indicating the estimation of 2.3 SG pore pressure and narrow window (0.07 SG).

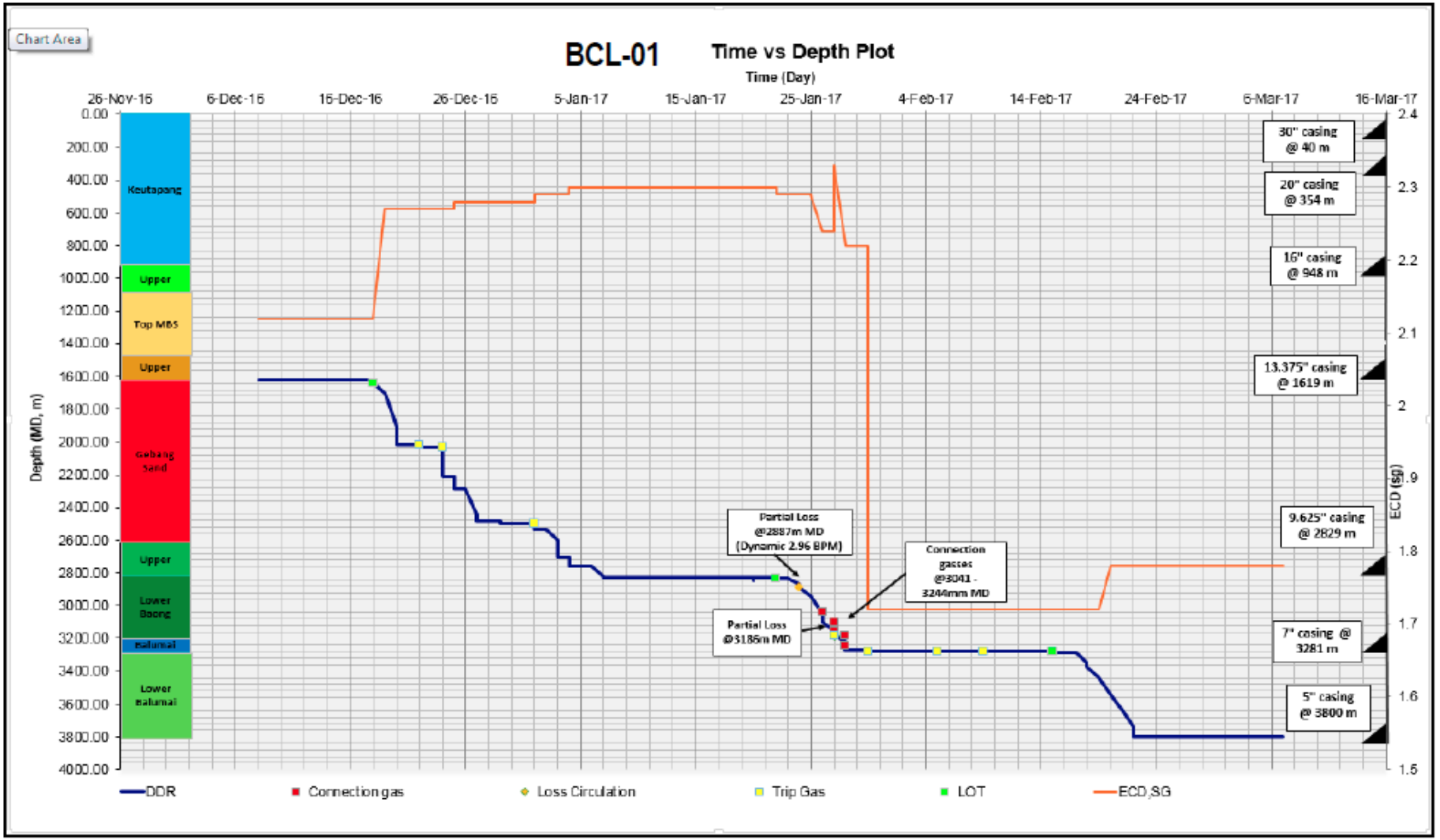

Figure 8. Time vs. depth chart of drilling events in well BCL-01.

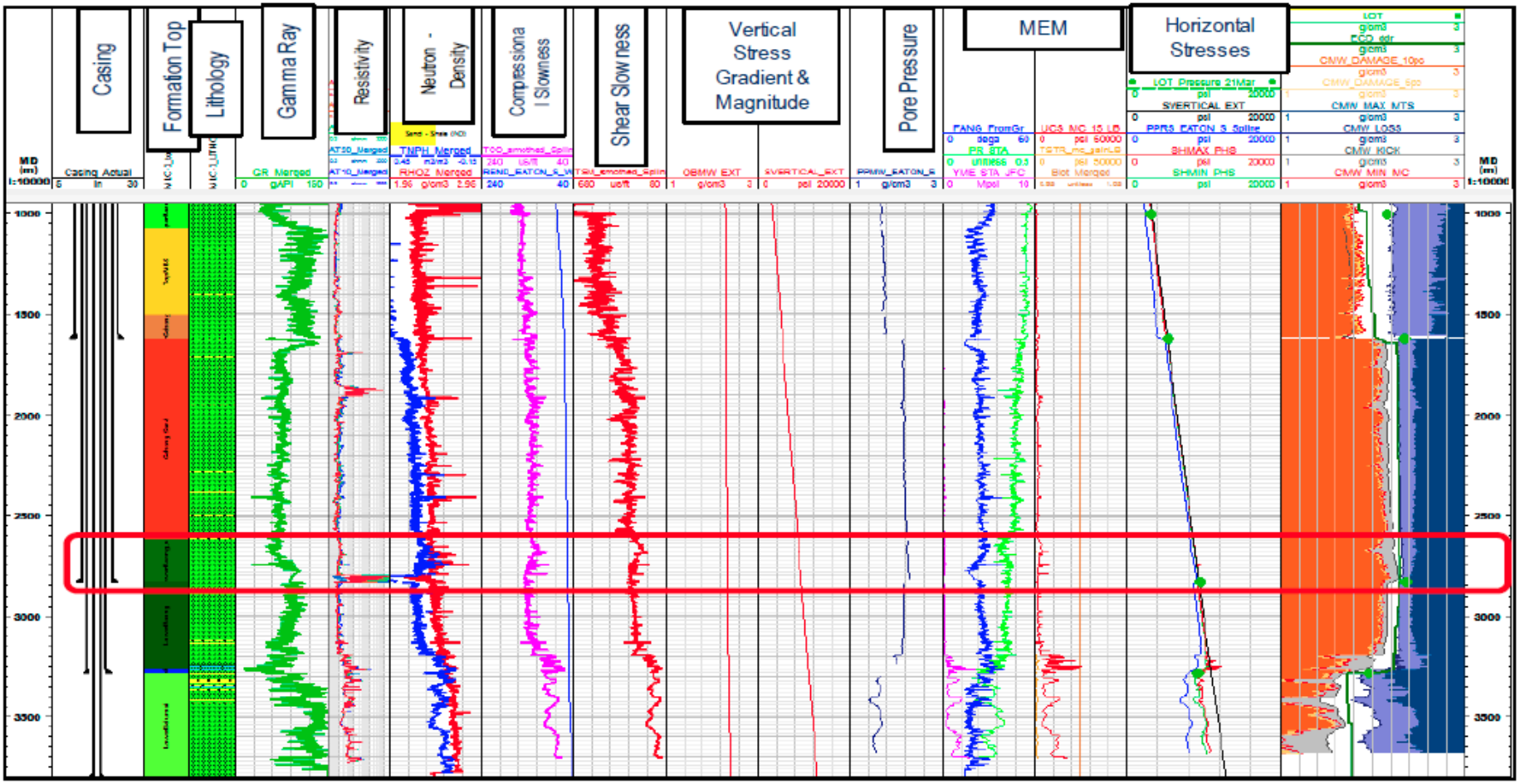

Figure 9. Actual well bore stability analysis of BCL-01. Red box is indicating the interval in the Lower Baong Formation with narrow mud weight window. Maximum pore pressure is 2.27 SG and fracture gradient is 2.33 SG.