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Challenges and Solutions Associated with Drilling Deviated Wells in Alternating Soft-Hard Formations – A Case Study from Onshore KG Basin, India*

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Abstract

Exploration is being done in Godavari Clay petroleum system of KG Basin to add new reserves with challenging drilling environment. Discovery of medium- sized fields with liquid hydrocarbon in the Coastal Tract, significant discovery of Ravva Field in the shallow offshore and some very exciting mega discoveries in deep offshore parts of the basin have made this youngest petroleum system, a very important one. The wells analyzed in this study had the primary objective of reaching the Matsyapuri/Ravva Formation, which is oldest lithological unit belonging to Miocene age. Due to logistics, positional, and geographical complications, directional wells were planned from a land site. This article investigates three lost-in-hole incidents and other drilling related NPT encountered in two directional wells. This study provides solutions through integration of geomechanics, drilling parameters, and mud rheology to assist in decision-making for future well planning.

Introduction

The cost of well construction can exceed budget dramatically if drilling operations are plagued by wellbore-instability problems and excessive time, and resources are needed to free stuck pipe, regain circulation, or clean the hole efficiently. Particularly, while drilling high-angle wells, wellbore-related issues, like hole cleaning, always remain the biggest challenge, especially with Kelly rig system where back-reaming operation cannot be performed in case tight spots are encountered. In such cases, RPM, flow rate, and good mud rheology are of utmost importance, which in turn govern the effective hole cleaning. These challenges, if not handled properly, leads to severe wellbore failure, shortening TD, sidetracking of the hole, pre-mature cancellation of the drilling program, and several other related problems. In addition, severe hole enlargement and rugosity through the eventual reservoir sections resulted in poor logging conditions and uncertain reservoir evaluation.

As a result, access and interpretation of the reservoirs, to prove and produce reserves, have been a major challenge in this region. To optimize drilling time, key is to predict optimal stable mud weight window. Wellbore stability analysis (WBS) is the key to the success of drilling exploration wells. The mechanical earth model (MEM) is the platform that determines a stable mud weight window using rock mechanical properties and a stress model (Plumb et al., 2000).

This article presents an investigation study where integration of geomechanics and drilling assisted in establishing the root cause for the lost-in-hole incidents. This study also provides inputs for future well planning and decision making.

MEM Construction and Wellbore Stability

Prior to drill a well, initial state of existing compressive stress in rock formation can be resolved in three components: vertical stress (σ_v), minimum horizontal stress (σ_h) and maximum horizontal stress (σ_H). As the well is drilled, stresses redistribute in the vicinity of rock with replacement of initial solid support of rockmass by mud pressure. The redistributed stresses can be resolved in the form of hoop stress acting circumferentially along wellbore, the radial stress and the axial stress acting parallel to wellbore axis. With well deviation, additional component of shear stress comes into play. If rock strength is enough to sustain redistributed stresses, either in compression or tension, wellbore will remain stable with present mud weight. Hence, computation of stresses becomes pivotal part of wellbore stability analysis.

The mechanical earth model 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 generalized workflow (Figure 1a) adopted is described as follows:

Data Audit

All available dataset ranging from geology, well logs, images, drilling events to calibration data (LOT, formation pressures), drilling parameters are collected and checked for quality. It is very important to create database in order to determine if critical data is missing; this might add uncertainty in the modelling. In this step, drilling issues encountered in different formations are analyzed.

Two L shaped directional wells (A & B) are considered for modelling in the study. They have a maximum deviation of 60^o and 48^o and drilled at an azimuth of~150^o and 108^o, respectively. In both wells, severe wellbore instability issues were encountered in Godavari Clay and Matsyapuri Sandstone Formation. Well A suffered around 16days of NPT, whereas well B had 100days of NPT. Both wells faced similar drilling challenges. Figure 1b shows drilling events evaluation plots for Well-B.

Rock Elastic and Strength Properties

Matsyapuri Sandstone is a very young formation and presents a good variation in rock strength, giving different stability behavior (Figure 2). These units consist of sand, shale and limestone sequence and pose a huge challenge when drilled at high deviation. They are challenging with the fact that shales require higher mud weight to minimize breakouts, and permeable normal-pressured sands have high risks of differential sticking. At high inclinations the stable mud weight window is further reduced effectively by more complex hole-cleaning requirements.

Vertical Stress Model

The in-situ earth stresses are primarily driven by the weight of the overburden sediments and fluids. For most sedimentary basins the overburden weight generates a vertical stress roughly equal to one psi/ft of overburden or depth. This value results from the integration of a bulk density log over depth. Vertical stress is determined by integrating the density log data from surface to the target depth including air gap for the well-A and B. Estimated vertical stress gradient varies in between 0.90psi/ft to 0.96psi/ft.

Pore Pressure Model

Pore pressure is estimated in shale sections using a log-based method (sonic compressional slowness) and calibrated direct formation pressure measurements in the sand section. Pore pressure is critical for the horizontal stress calculations and is found to be hydrostatic in all the formations encountered.

Horizontal Stress Magnitude and Orientation

In absence of multi-arm caliper or image file, breakouts analysis could not be performed and hence minimum horizontal stress orientation is assumed to be N110^o, based on structure map, literature, and local experience.

After these steps, a Mohr Coulomb failure criterion is used to history match the predicted failures, from estimated rock properties and stresses with drilling events and caliper, to validate model, as shown in Figures 3 and 4. Predicted failures (track 7) based on the model show good match with measured caliper (track 8), validating the model and associated parameters. Analysis for wells A and B clearly shows over-gauged hole condition with stuck pipes, tight hole incidents in Godavari Clay and Matsyapuri Sandstone. There is need of higher mud weight to minimize breakouts in weak shale layers. At the same time, differential sticking and formation damage need to be avoided in sand layers present in Matsyapuri Sandstone Formation. Noninvasive fluids will be helpful to avoid fluid loss and thick mud cake.

Investigation of Drilling Events in Well-A

Well-A tackled held-ups while lowering logging tools in 12.25” section. These were encountered in lower strength shales of Godavari Clay and Matsyapuri Sandstone Formation which have over-gauged hole due to shear failure (Figure 3(a)). In 8.5” section string got differential stuck while making connections due to overbalance of 0.3SG in sands (Figure 3(b)). In this case string was released during 15minutes of soaking operation performed after reducing the mud weight from 1.3SG to 1.26SG.

Investigation of Drilling Events in Well-B

Well-B with stuck pipe incidents led to 3 LIH and multiple sidetracks, two in 12.25” and one in 8.5” section. First two stuck pipe incidents occurred in 12.25” section, both while performing wiper trip (Figure 4). MEM and WBS results show that 1.11SG to 1.15SG mud weight used during drilling of 12.25” section was insufficient to prevent shear failure. Consequently, over-gauged borehole condition is seen throughout shales. Situation was aggravated by use of water-based KCL-polymer mud. Furthermore, drilling parameters RPM (~60-80) and discharge rate (~750GPM) were not sufficient to lift the cuttings (Figure 5). It resulted into formation of cutting beds also indicated by rise in ECD. During pulling out operation with circulation, these beds were disturbed causing pack-off.

After unsuccessful fishing operations hole was sidetracked using motor and directional drilling assembly with SOBM mud. This time drilling started with higher mud weight of 1.22SG and with optimized drilling parameters. RPM (~100-120) and discharge (~850GPM) were improved after the first incident and were nearly enough to lift all the cuttings. Then, also, stuck occurred in 1st sidetrack while performing wiper trip with circulation. String downward motion after the stuck was restricted, and circulation was possible. All efforts of freeing the pipe were in vain. Post-drill MEM evaluation shows mud weight could not have prevent shear failure in shales; this required a higher mud weight of 1.3SG to 1.4SG. On the other hand, stronger sands were intact. In addition, looking at the drilling parameters suggests stuck origin is of mechanical and wellbore-geometry-related issue (Figure 6).

Later 9.625” casing was lowered after partial fishing operations and started drilling second sidetrack hole in 8.5” phase with 1.24SG SOBM. After drilling further 430m into the Matsyapuri Sandstone, string again got stuck during the pipe connection. The primary drilling data and log analysis indicate presence of relatively interbedded clean formation with high invasion profile (permeable zone). During this event, string was static, and mud weight required in sands was well above formation pressure~1.02SG, causing a differential pressure overbalance of ~0.22SG. String rotation seized just after the stuck, but circulation was established. All these lines of evidence suggest that stuck was of differential nature (Figure 7).

Well was sidetracked in 8.5” section for the third time. Drilling started with improvised drilling parameters and comparatively lower mud weight of 1.2SG down to its updated target depth of 2388m MD.

It should be noted that WBM drilling with low rig capacity limited the drilling further for the first mother-bore, where first 12.25” stuck happened, and later in 12.25” ST and 8.5” section, those conditions were overcome by using SOBM and after optimized rig capacity and safe drilling practices. However, post- stuck analysis revealed that the second LIH happened dominantly because of mechanical/geometrical (ledges formed due to interbedded soft and hard formations) stuck mechanism. This was f ollowed by third string stuck where higher overbalance condition caused differential stuck.

Conclusions

Drilling through geological formation with varying grain size, rock strength, and permeability pose significant risk while drilling at high angle. Combination of geomechanics parameters, BHA design, mud fluid loss property, and hole-cleaning practices can pave way to overcome challenge. Differential sticking, cavings, and poor hole cleaning are key reasons for stuck pipe.

Recommendations for Drilling Future Wells in This Area

Future wells in this field need proper planning and analysis to have the best drilling solution which should include:

- Pre-drill MEM for optimizing the mud weights.
- High capability rigs to drill deeper formation at high angle, high drift and ERD type wells to achieve longer destination.
- Proper drilling parameters are required for hole cleaning to prevent the accumulation of cavings and cuttings on the bottom of the borehole which poses a serious threat of stuck pipe.
- Optimizing well design, mud system, wellbore contact of BHA, and operations will help in preventing differential sticking challenge.
- Real time ECD, torque and drag monitoring and stuck pipe checklists. In future wells there needs to be a limit set on ECD limit, which as a roadmap alongside with real time torque and drag data needs to be followed while drilling and while tripping out of the hole.
- Hazards identified to the well planning team: drilling at high angle (40-60^o.) through a problematic shale and drilling through a permeable sandstone known to be prone to differential sticking.
- Trajectory should be chosen if possible either lower than 45^o or higher than 65^o to avoid hole cleaning issues with more breakouts at lower rock strength, resulting in cutting beds.

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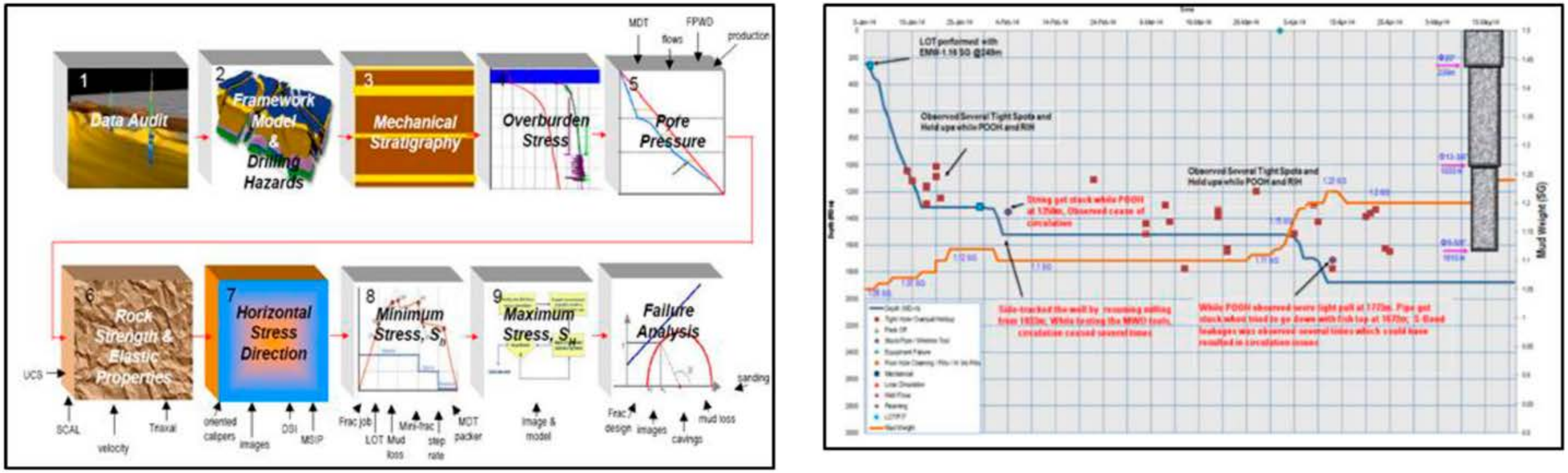


(a) (b)

Figure 1. (a) Workflow for Mechanical Earth Model and (b) Drilling history review for Well-B.

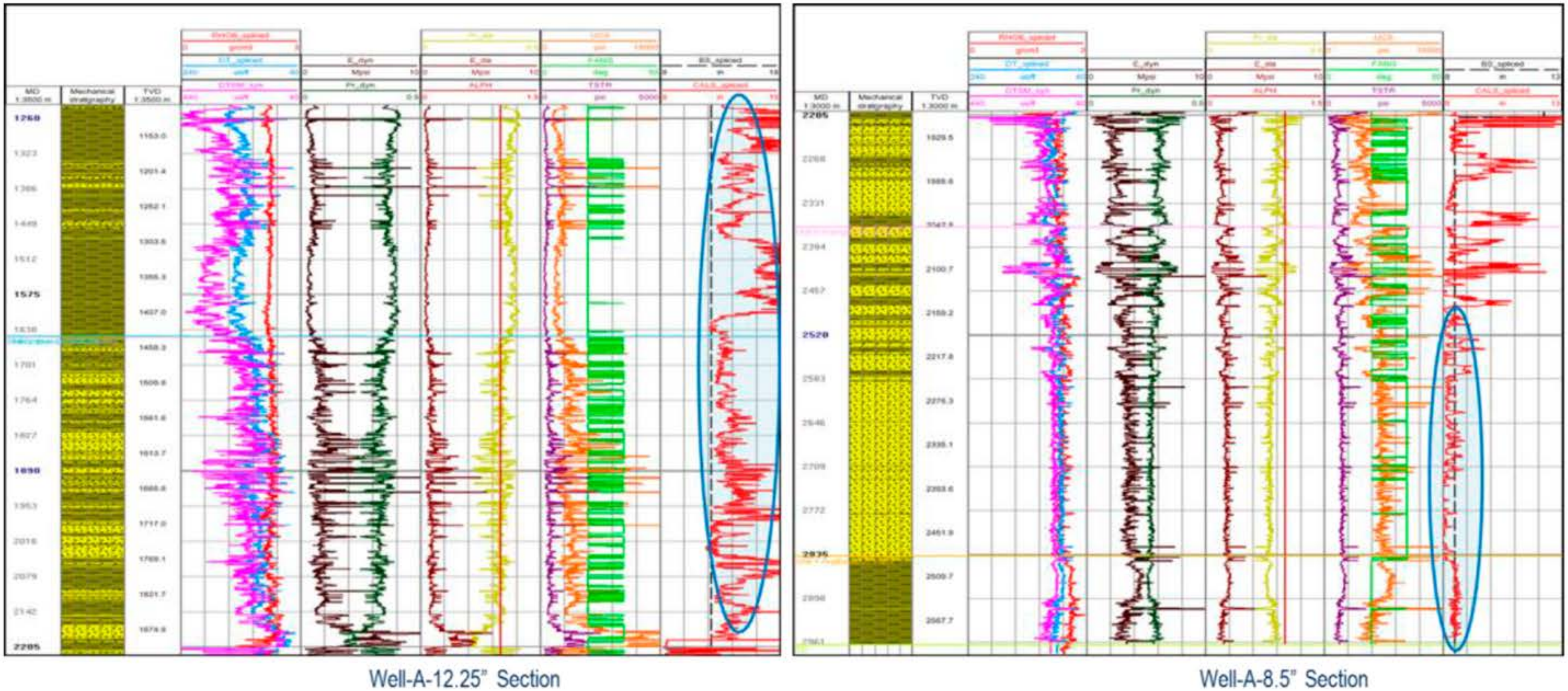


Figure 2. Rock elastic and strength properties.

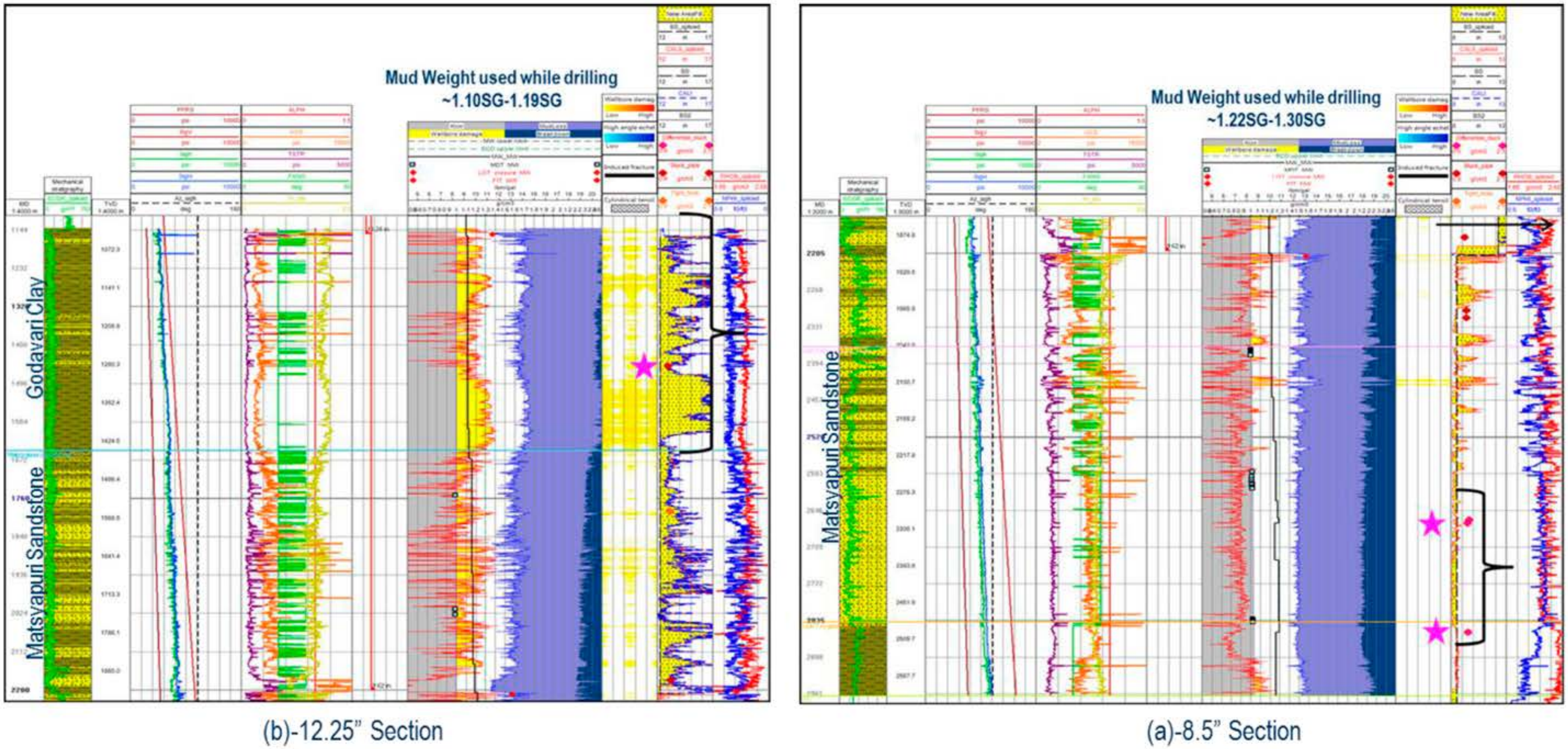
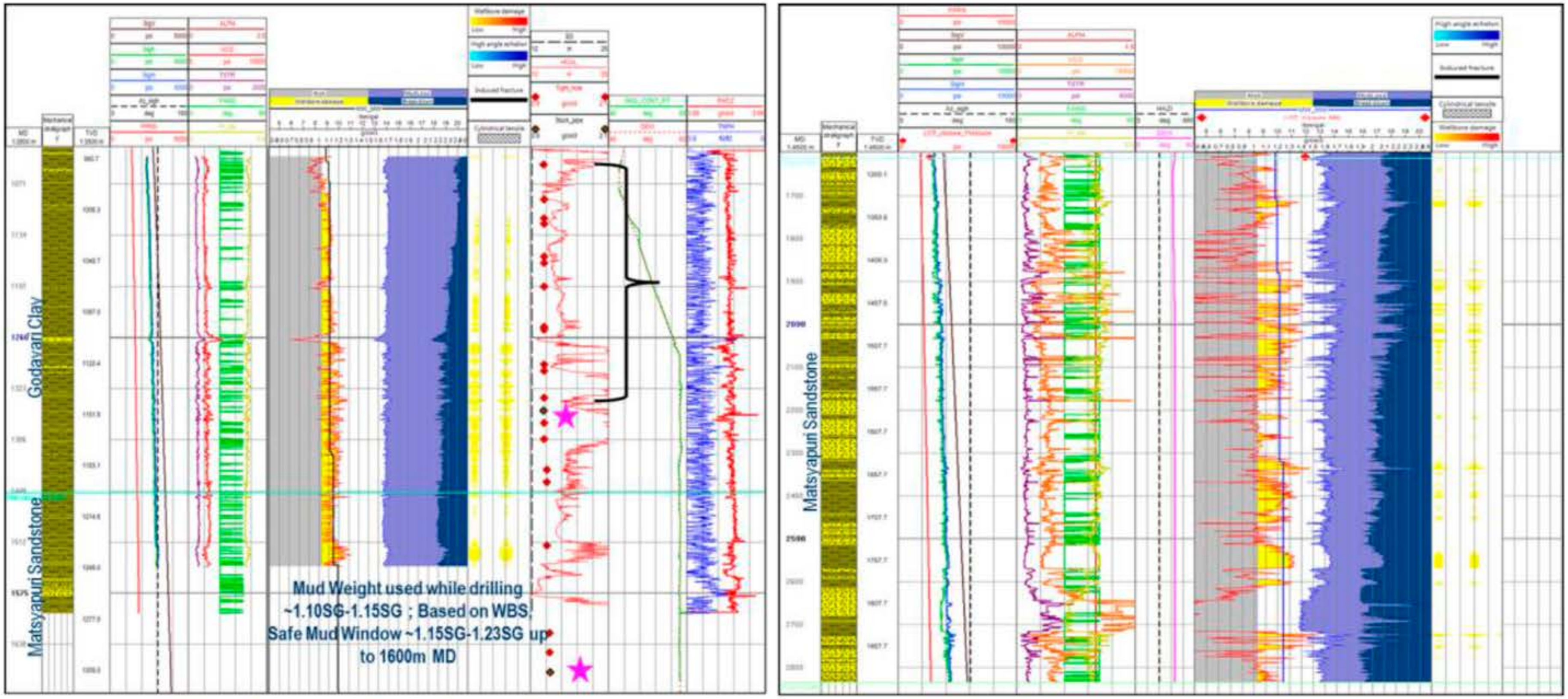


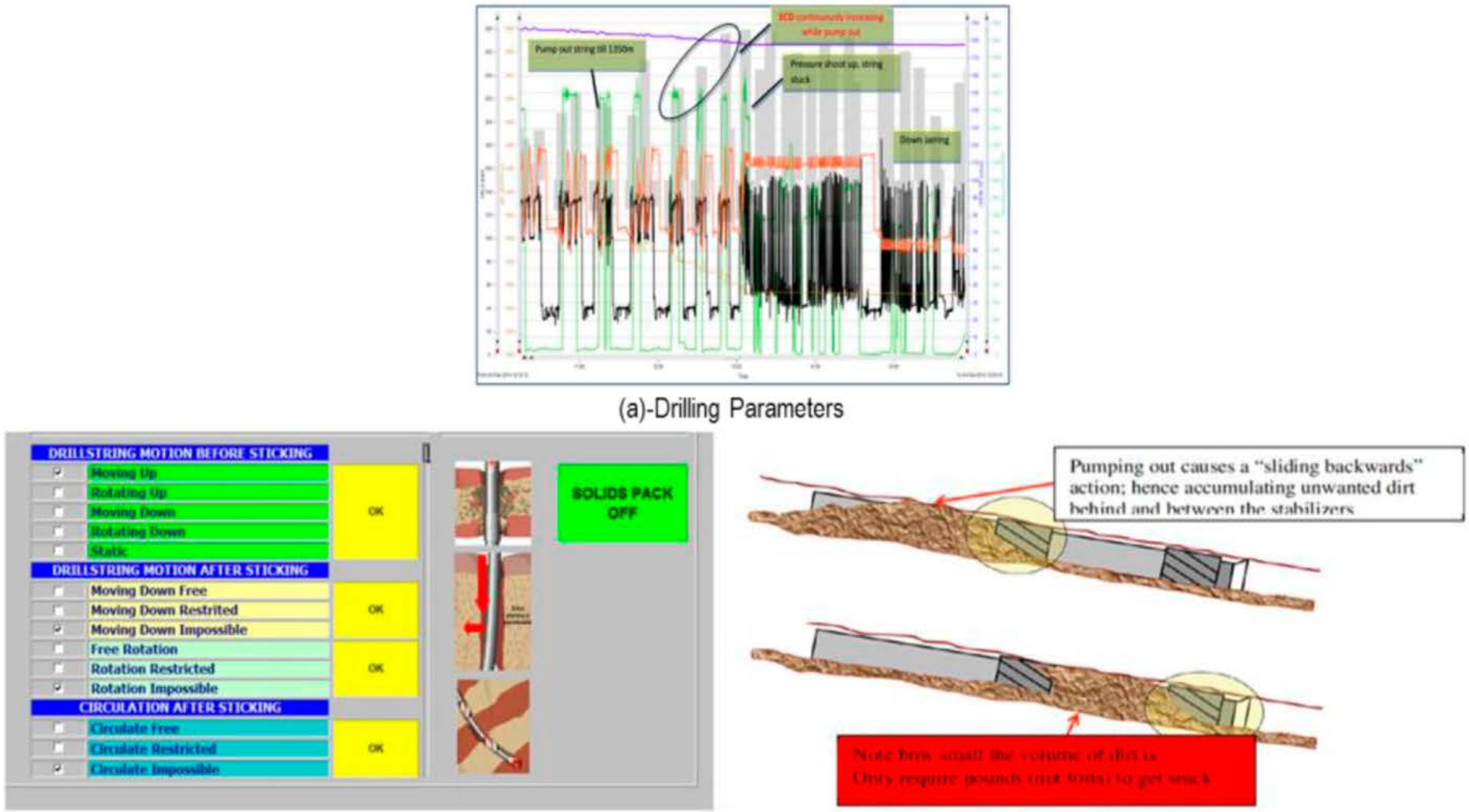
Figure 3. Wellbore Stability Model for Well-A.



(a)-WBS Model Prepared for Godavari Clay and Matsyapuri Sandstone based on data acquired in Well-B

(b)-WBS Model Prepared for Matsyapuri Sandstone based on offset well Data

Figure 4. Wellbore Stability Model for Well-B.



(a)-Drilling Parameters

(b)-Stuck pipe mechanism identification

(c)-Cutting accumulation while pumping out hole

Figure 5. First stuck incident -Identification of stuck pipe mechanism.

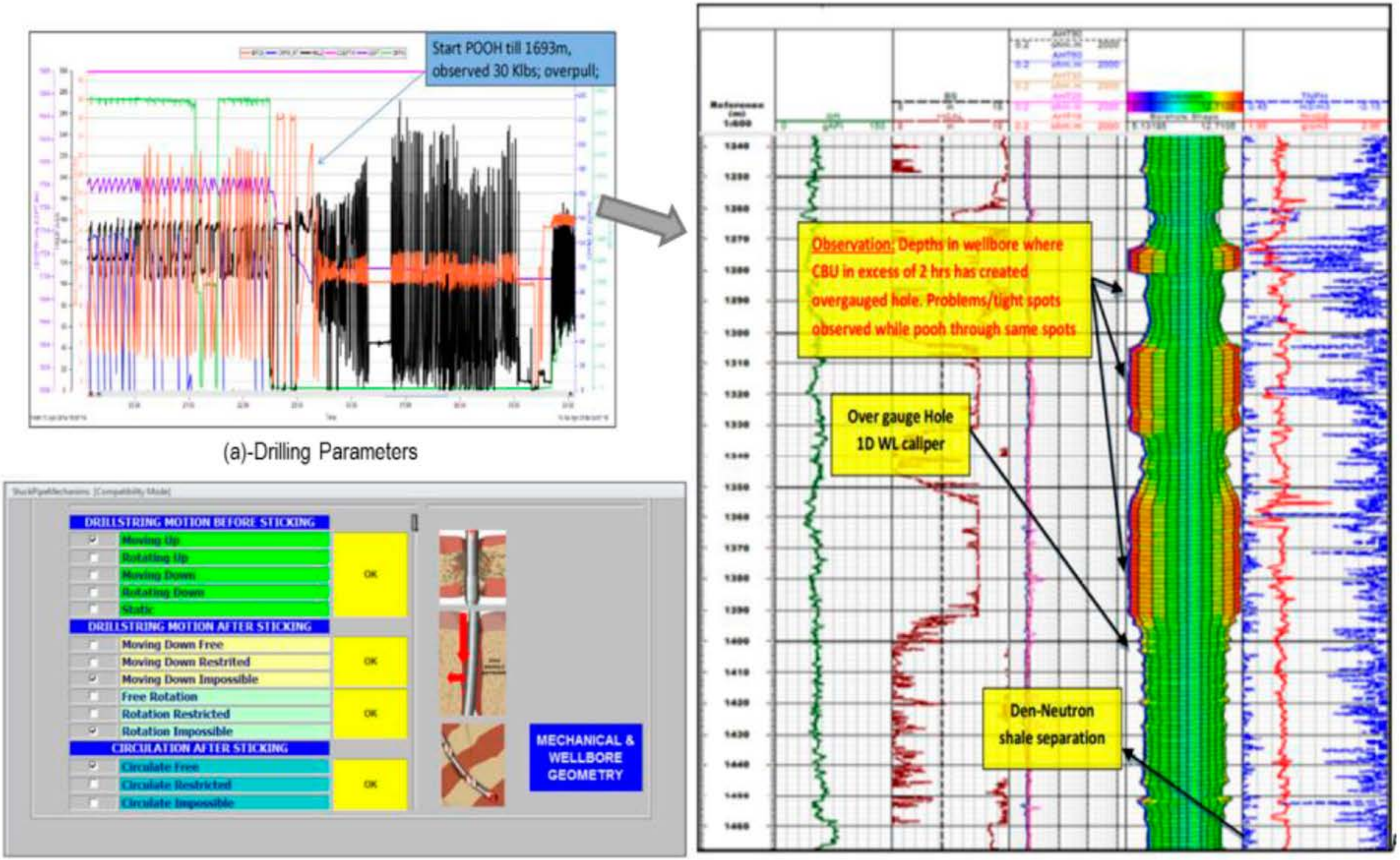


Figure 6. Second stuck incident -Identification of stuck pipe mechanism.

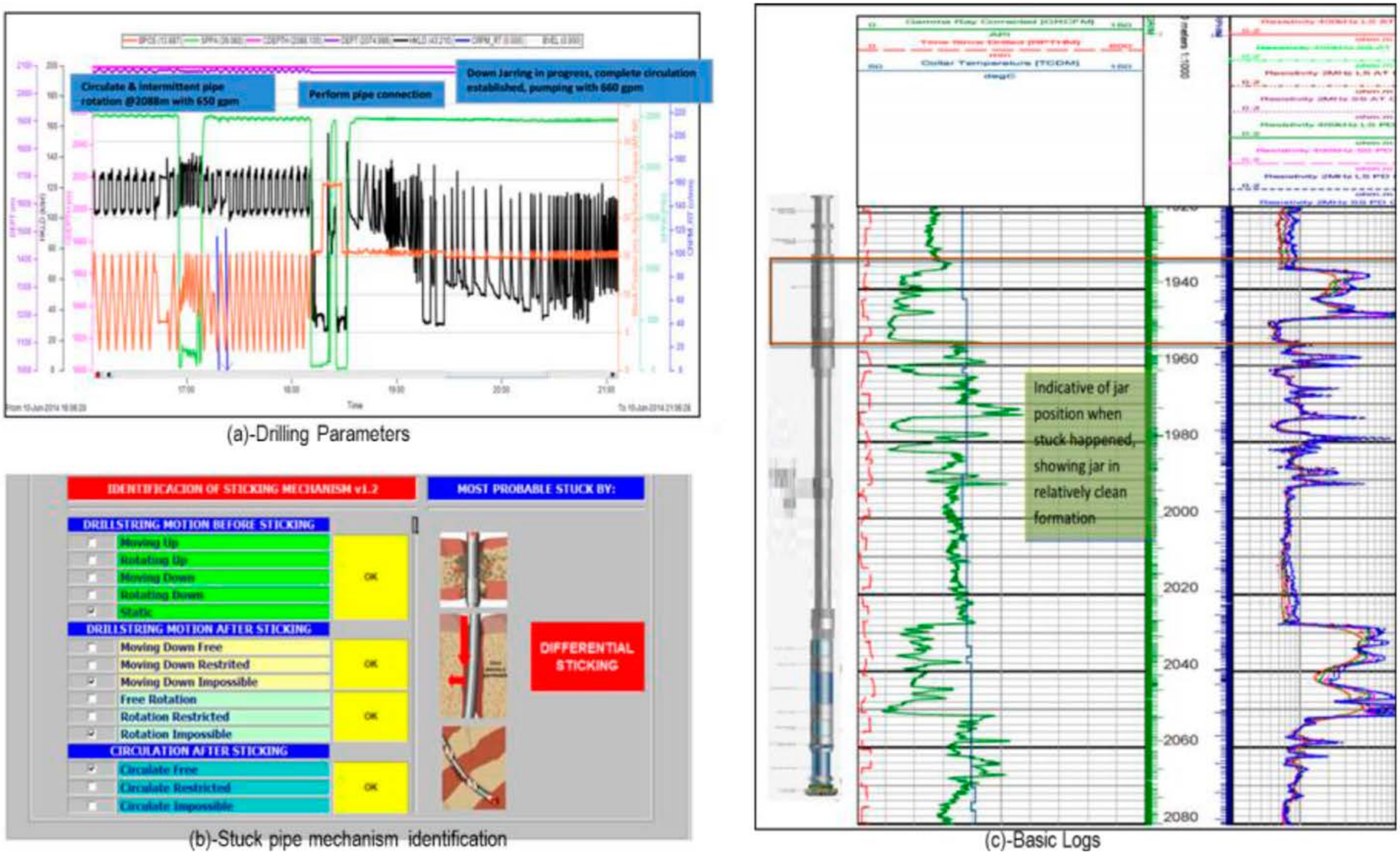


Figure 7. Third stuck incident -Identification of stuck pipe mechanism.

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