Above, Through and Below Trap - Integrated Geomechanics Understanding and Drilling Solutions for Kutch & Saurashtra region

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Keywords

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Summary

Formations encountered in the Kutch & Saurashtra Basin exhibits diverse drilling, logging, cementing and completions related challenges. Data scarcity in the region, demands rigorous planning for the upcoming wells with detailed analysis of hazards associated with the overburden and reservoir rocks. These challenges are identified with solutions associated with three distinct geological sequences. Integrated geomechanical analysis incorporating geophysical, geological and drilling parameters is conducted for the improvement in drilling performance, well condition and ROP.

A customized geomechanical workflow has been adopted to construct Mechanical Earth Model (MEM) for 15 wells across the basin. Wellbore stability events related to geomechanics were re-produced and analyzed. The cause of the events was established and mitigatory methods were proposed.

In addition, stress orientation along the wellbore trajectory and across the basin were estimated using breakouts identified on images and multi-arm calipers. Fast shear azimuth from Dipole Shear Sonic anisotropy analysis were also integrated to provide more robust and accurate estimates.

Wells in the region are characterized by slow ROP, high torque and drag, wellbore instabilities (severe held ups, cavings, stuck pipes, string stalling etc.) and challenges while logging and running casing. Study has characterized these challenges and required solutions linked to the existing three geological sequences They are weak Tertiary, Late Cretaceous Deccan Trap and Early Cretaceous to Jurassic clastic formations.

Tertiary formations are relatively weak (UCS~300 to 1500psi) and prone to sanding and cavings due to breakouts. MEM predicts that shear failure can be prevented by use of 10ppg to 11ppg mud weight.

The formations below Trap are commonly called Mesozoic. The Deccan Trap and Mesozoic formations are extremely tight, highly stressed, faulted, fractured and are also of HPHT nature in few wells. Rock strength shows a wide variation (UCS~5000psi to 25000psi) making bit selection a difficult. Borehole failure is complex and cuttings analysis shows the signature of both shear and weak plane failure. Fractures on the image logs, rotation of breakouts, and fast shear azimuth supports this theory. Mixing fracture sealing agents along with use of optimal mud weights is found to be the most likely drilling solution.

Study assisted in drilling of two successful wells wherein significant improvement in borehole condition in both Tertiary and Mesozoic sequence was achieved. An attempt has been made to have an in-depth knowledge of geomechanical aspects of the basin by integrating huge volume of data from 15 wells across the basin. Both well centric and field wide observations have been made based on advance acoustics, image and geochemical data.

Introduction

Kutch & Saurashtra Basin, located in shallow water off the coast of Gujarat in western India, is characterized by distinct geological sequences having varied lithology. The shallower formations – Kandla, Chhasra, Godhra, NS-Tuna, Fulra, Jakhau and Nakhatarana are characterized by Clay, Claystone, Sandstone, Siltstone, shale and carbonate facies. The underlying Formation is Deccan Trap which is up to 2500m thick and primarily consists of Basalt with intervening weathered Basalt. The Mundra, Bhuj, Jhuran, Jumara and Jhurio Formations belonging to Lower Cretaceous and Jurassic age comes under Mesozoic Sequences. Stratigraphic map of the field is shown in Fig 1.

Kutch & Saurashtra Basin is relatively unexplored with limited drilling and logging data available specially in Mesozoic sequences. Hence, planning for upcoming wells is always a challenge given the hazards associated with the overburden and reservoir rocks. These challenges are distinct and are associated with above discussed three broadly classified litho-units or sequences. Overall 15 wells have been analyzed in the region. In the section below these challenges are summarized along with probable solution and impact.

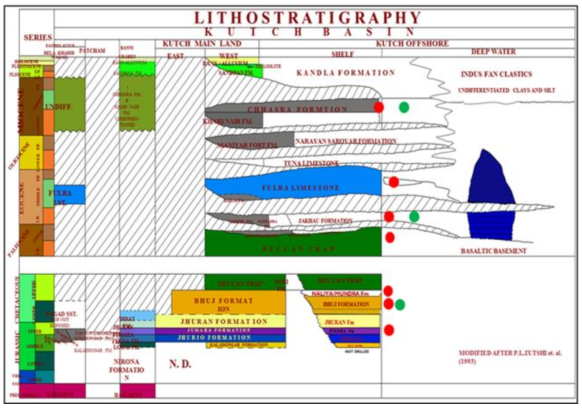
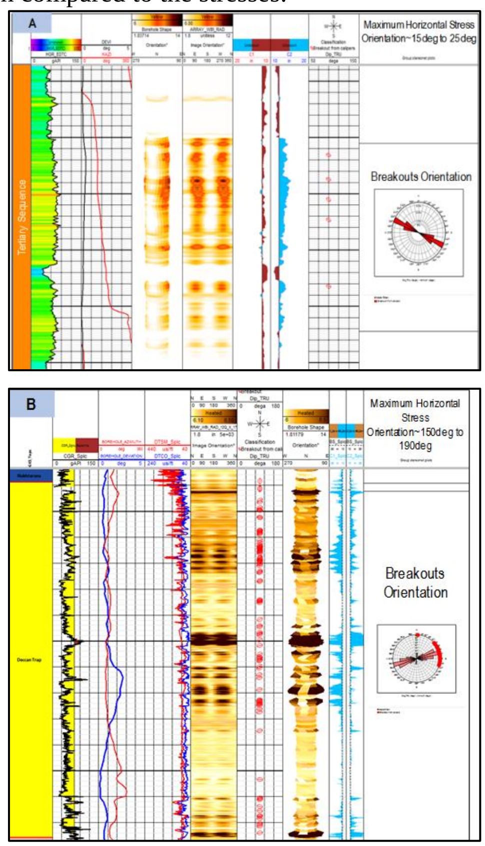


Fig. 1: Kutch & Saurashtra Basin stratigraphic map

Observations and Identified Challenges

Tertiary Formations: Drilling through these formations is relatively fast with average ROP in the range of approximately 5-15-m/hr. Key challenges and observations based on the analysis are listed below:

- Formation pressure gradient is hydrostatic (~8.6ppg) in all the wells analysed.
- Four arm calipers, image logs and fast shear azimuth has been used to establish the orientation of horizontal stresses. In the wells analysed, it is found that maximum horizontal stress orientation varies in the Tertiary sequences from -15deg to 25deg from North. Minor stress rotation is also observed suspected due to presence of sub-surface faults (Fig.2a).
- Mud losses are encountered in some of the wells in Limestone facies. These losses are primarily due to the vuggy and cavernous nature of Limestone. They are cured by use of LCM materials.
- Borehole collapse (shear failure) is faced in the weak shales/clay/claystone lithofacies. Fig.3 shows the 1D-Mechanical Earth Model (MEM) constructed for these shallow Formations. Held ups and stuck pipe issues are correlated in these overguaged parts. Shear failure can be prevented by use of optimum mud weight in the range of 10ppg to 11ppg.
- Sanding issues are observed on application of drawdown pressure across the target sand intervals. Analysis shows that some sands are relatively weak when compared to the stresses.



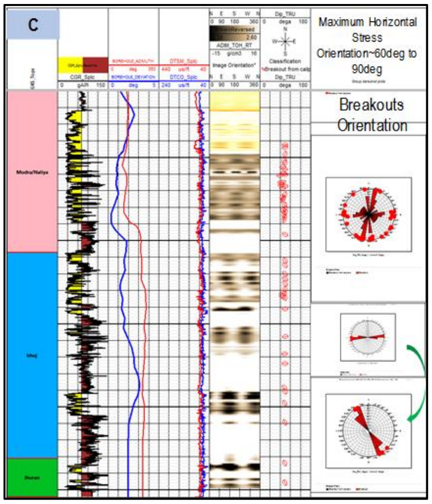


Fig. 2: Stress orientation observed in the wells analysed in (a)Tertiary Sequence (b)Deccan Trap and (c) Mesozoics Sequence

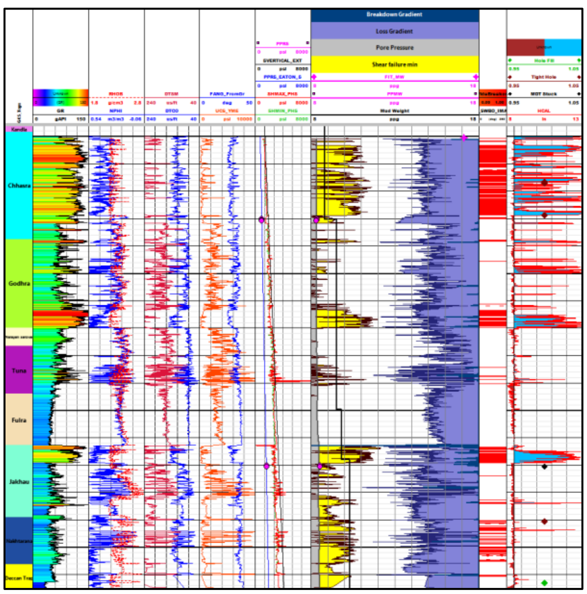


Fig. 3: Mechanical Earth Model (MEM) for Tertiary Sequence Formations

Deccan Trap Formation: This formation is heterogenous in nature as it was formed by multiple Basaltic flows with enough time in-between for the weathering agents to do their task. Weathering has induced large variation in rock strength (difference >~6ksi). This Formation offers serious challenges to all the phases of the well i.e. while drilling, logging and casing running. ROP in Deccan Trap is very low (<2m/hrs) and results in number of bit trips. Key challenges and observations based on the analysis are listed below:

- Mostly formation pressure gradient is hydrostatic (~8.6ppg) in the Deccan Trap Formation. However, in one well water influx was seen which was controlled by increasing the mud weight to 10.2ppg from 9.6ppg. Image data shows that the basalt is intensely fractured and this isolated incidence might be because of fluid charging as it is not observed in the other wells.
- Cavings are observed on the shaker while drilling basalt. Four arm caliper log data reveals occurrence of borehole ovalization (**Fig. 4a**). MEM for basalt (**Fig.4b**) is unable to predict all the failures seen on the calipers, suggesting that borehole failure is governed by not only stresses. Other factors contributing are fractures and weathering of the rock. On closer analysis of borehole failure with mud log lithofacies, it is seen that shear failure is mainly seen in intact basalt. Other petrophysical logs also correlate with this hypothesis. Less number of fractures are seen in weathered basalt on image also support this hypothesis.
- Losses are observed while drilling. MEM indicates (**Fig. 4b**) that mud weight is crossing loss gradient and opening the already existing fracture.
- Difference in deep and shallow resistivity in basalt also indicates mud invasion through fractures. The contrast between the resistivities decreases in the weathered zone.
- Borehole damage is a combined effect of occurrence of failure plane initiated by shear failure, pre-existing fracture/fault planes, interface between the intact and weathered basalt. Increasing mud weight in basalt might aggravate the borehole failure as invasion will further increase. Increase in mud weight would be beneficial only if mud is strengthening or healing the open fractures.
- In the wells analysed, stress direction rotation is observed inside Deccan Trap Formation on four arm caliper and image log. **Fig. 2b.**
- Basalt is by nature strong, hard and abrasive. Drilling in Basalt formation with normal TCR and PDC bit is giving very poor ROP and bit wear resulting in frequent long bit trips. An engineering solution was tried by introduction of StingBlade* PDC bit which is designed to work in these kinds of very hard formations. A comparison of meterage drilled by Stinger-PDC and TCR is shown in **Fig. 5**.

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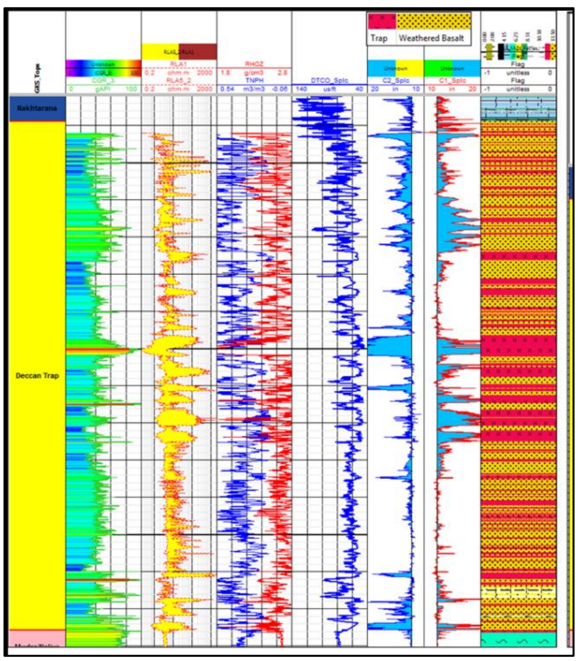
Considering the low ROPs in this Formation, it is imperative to carry out detailed bit optimization studies.

Mesozoic Formations: These are the oldest litho-units drilled in the basin and are of primary importance because of existence of potential hydrocarbon pool.

- In the upper interval of Mesozoics, rock strength governs the shear failure of the rock and failure is observed both in sands and shales. In the lower intervals the, scenario is unique. Stiffer sand rich layers, which bear higher horizontal stress anisotropy, show distinct and consistent breakouts. Less stiff interlaying shales indicate an in-gauge hole. This observation is clearly observed **Fig. 6**. Due to this phenomenon, more than ~60% of the wireline pressure measurements in the target sands fail due to lost seal (SPE-185432).



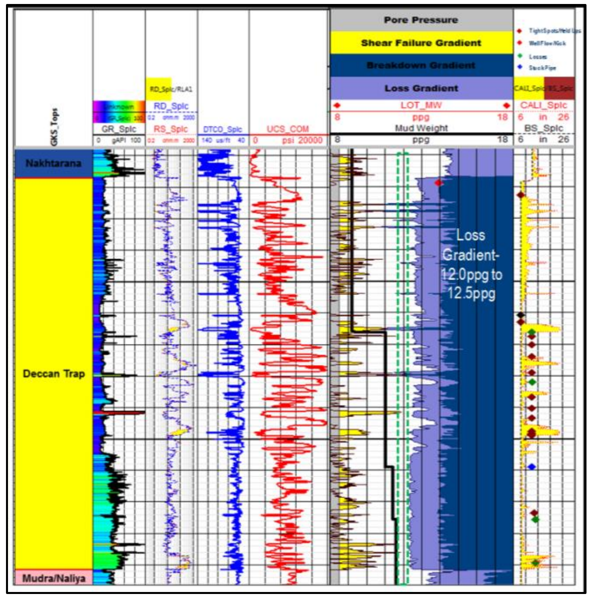


Fig. 1: (a) Comparison of basic logs (Gamma Ray, Deep and Shallow resistivity, density and neutron porosity, compressional slowness, calipers) and mud log lithofacies **(b)** Basic logs and MEM outputs and stable mud weight window

- Four arm caliper, image and density image shows the occurrence of breakouts. Breakouts are Stress rotation is observed in Mesozoics. **Fig. 2c** shows the rotation of breakouts with depth. Most probable explanation for such variation in stresses is the presence of fractures and faults which are seen on image logs.
- Wellbore stability analysis shows that mud weight required to prevent shear failure in Mesozoics is in the range of 13ppg to 14.5ppg.

Impact and Way Forward

For proper field development it is required to understand the Formation behavior.

- Shear failure observed in Tertiary and Mesozoic sequences can be controlled by optimizing the mud weight. Fig. 7 shows two examples where borehole condition is improved as compared to offset wells.

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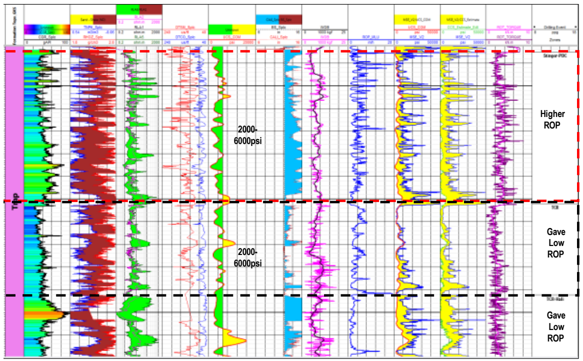

Fig. 2: Comparison of bit performance with Mechanical Specific Energy, petrophysical and rock mechanical properties. Last track on the plot shows the bit type used.

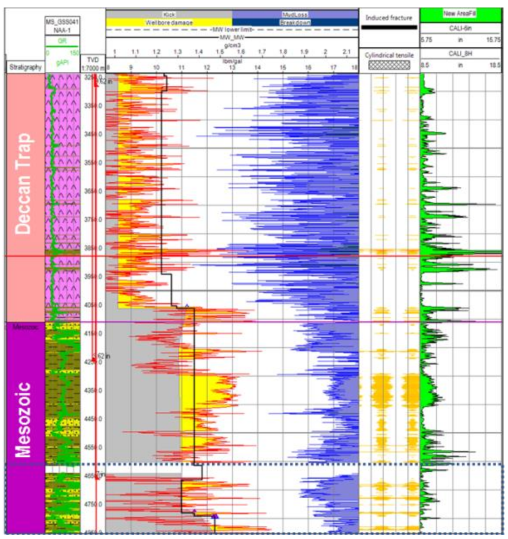

Fig. 3 (a) Stable mud weight window in the upper Mesozoics

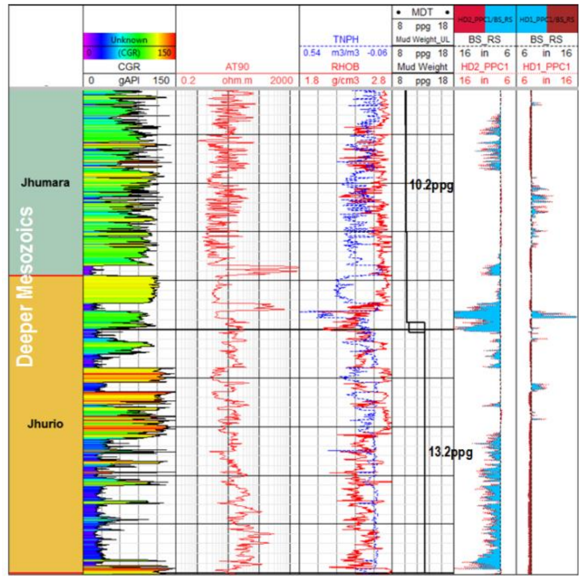

Fig. 4 (b) Correlation of breakouts with basic logs in deeper Mesozoics.

- Pore pressure is variable across the Basin. Most of the wells on the north side (Fig.8) have reached their target depth in Mesozoic Formation with mud weight of 10.8ppg to 12.3ppg. Maximum possible pressure in these wells is approximated to be around ~10-20% above hydrostatic pressure.

- In the offset of well-B, increase in pore pressure is indicated by gas influx events in bottom of Deccan Trap (~11.2ppg) and Mesozoic formation (~12.3ppg). However, DST across perforated interval in Jurassic reservoir indicates hydrostatic pressure. In presence of conflicting calibration measurements, pore pressure could not be tightly constrained. Hence, MEM was sensitized for three pore pressure models.

- In another case of well-B (Fig.9), well flow event was encountered, once at the bottom of Deccan Trap Formation and then inside Mesozoics. Well was finally controlled with 14.2ppg mud weight. Bottom hole gauge data also confirms the presence of high pressure in this well. Density slowness crossplot (Hoesni, 2004) indicates a different type of mechanism other than undercompaction. Further analysis is required to establish the overpressure mechanism in the Basin.

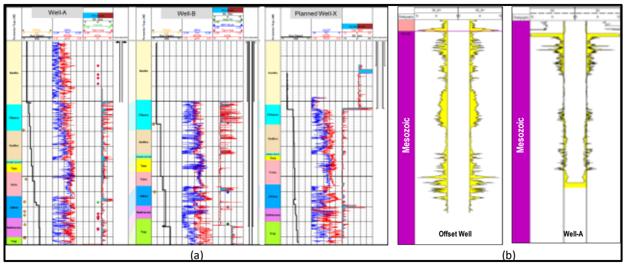

Fig. 5 Improved borehole shape observed in (a) Tertiary section and (b) Mesozoic section(SPE-185432) in comparison to offset well.

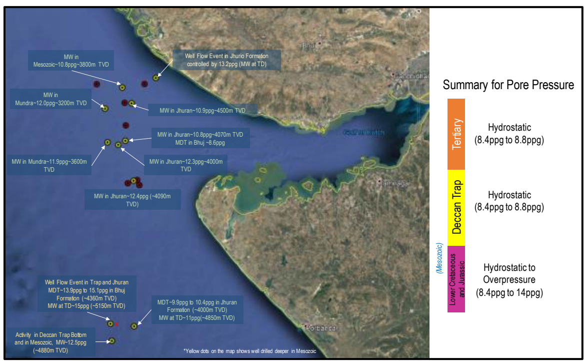

Fig. 6: Pore Pressure summary map of Kutch & Saurashtra region.

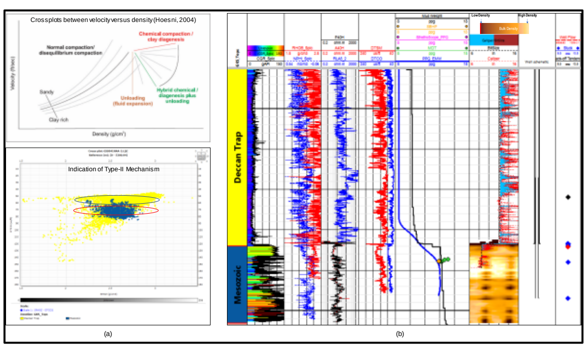

Fig. 7(a) Crossplots between velocity versus density (Hoesni, 2004) **(b)** Final pore pressure profile for Well-B

- Variation of stresses is observed in the studied wells suggesting presence of faults and fractures in Deccan Trap and Mesozoics Sequences. 3D MEM is required to capture and quantify the impact of these sub-surface features on current day stresses.
- Mud design for Deccan Trap Formation is also a challenge. Based on the wells analysed, invasion of mud is very evident. As the formation is extremely hard and fractured, proper bridging and sealing agent is required.
- Customised Stinger bit has demonstrated that drillability of basalts, can, not only be improved considerably, but also there is enormous scope of further improvement. Such drilling bits should be used in tandem with motor and compatible drilling assembly. In terms of relative comparison between normal PDC and TCR, PDC or its equivalent is performing better than TCR bit
- Key challenges experienced in Kutch Saurashtra region are summarized in **Fig-10.**

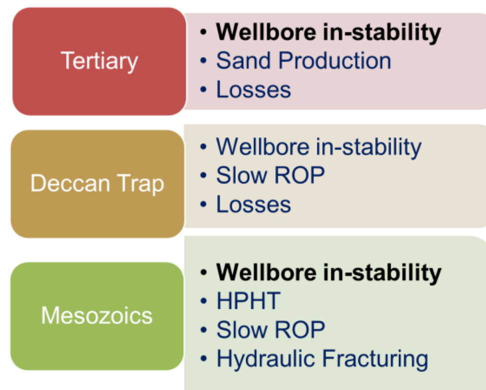

Fig. 10: Summary of key challenges associated with formations in Kutch Saurashtra Region

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