computed values of UCS, Cohesion and Friction Angle were calibrated with lab data.

$YM_{static} = 0.0006*(YM_{dynamic})^{2.8977}$

$PR_{static} = PR_{dynamic}*0.65$

$UCS = 4.242 * YM_{static}$

$TSTR = 0.1 * UCS$

$FANG = 19 + 31.172\,(1 - \Phi - V_{clay})^2$

$$COH = \frac{UCS}{2\left[\sqrt{(1+(\tan FANG)^2} + \tan FANG\right]}$$

Horizontal Stresses: The knowledge of the magnitude of these stresses enables us to estimate the hoop stress acting on the periphery of the wellbore so that one can predict whether the rock with a given strength and given mud weight will fail or not. Besides magnitude, the direction of horizontal stresses becomes all the more important when we plan to drill deviated and horizontal wells. In a normally faulted basin, the preferred well azimuth is the orientation of Shmin whereas in strike-slip or thrust fault basin the preferred direction is that of SHmax.

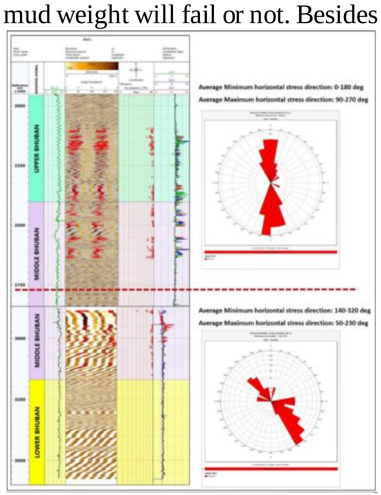

Figure 9: Minimum Horizontal Stress Direction in KH-B

Direction of Horizontal Stresses: KH-A, KH-B, KH-D & KH-F have resistivity image data recorded, which has been studied thoroughly for prevailing principal stress directions in study area. By analyzing borehole image data in well KH-B, it is observed that in the middle part of Middle Bhuban Formation, there is a distinct change in dips orientation and magnitude, and change in stress direction as inferred from breakout analysis (Fig.9). This indicates presence of thrust in the vicinity. Direction of maximum horizontal stress in Upper Bhuban and upper part of Middle Bhuban is 90º N. It changes to 50º N in lower part of Middle Bhuban and Lower Bhuban formation.

Stress magnitude estimation: In this study, a poro-elastic horizontal strain model (Fjaer et al., 1992) is used to estimate the magnitudes of the minimum and maximum horizontal stresses.

$$\sigma_h = \frac{\nu}{1-\nu}\sigma_v - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\epsilon_x + \frac{\nu E}{1-\nu^2}\epsilon_y$$

$$\sigma_H = \frac{\nu}{1-\nu}\sigma_v - \frac{\nu}{1-\nu}\alpha P_p + \alpha P_p + \frac{E}{1-\nu^2}\epsilon_y + \frac{\nu E}{1-\nu^2}\epsilon_x$$

Where σh = minimum horizontal stress, σH = maximum horizontal stress, σv = overburden stress, α = Biot's elastic coefficient, Pp = pore pressure, εx = strain in the minimum horizontal stress direction, εy= strain in the maximum horizontal stress direction respectively.

Calibration of the Minimum Horizontal Stress Magnitude (Shmin): The most reliable measurements of in-situ least principal horizontal stress are those provided by analysis of minifrac and/or extended leak-off test (XLOT). Leak-off test data available for studied wells was used to calibrate Shmin (Zoback, 2007).

Calibration of the Maximum Horizontal Stress Magnitude (Shmax): Hottman, Smith et al. (1979) used variations of the occurrence of breakouts (as indicated by wellbore spalling) or drilling induced tensile fractures with changes in mud weight to make an estimate of the maximum horizontal stress, after first constraining the other parameters associated with wellbore failure (Zoback, 2007).

Wellbore stability analysis and 1D Geomechanical Model Calibration: Using the computed rock properties and horizontal stresses, wellbore stability analysis tells us how good the MEM is by comparing the predicted wellbore stability with the drilling events observations, breakouts or drilling induced tensile fractures observed on image or caliper logs. Generally, the model can be verified against these compressive and tensile failure occurrences as observed in image logs or caliper logs, if coverage is good (Fig. 10). Table-1 gives optimum mud weight window for smooth drilling in 12.25'' and 8.5'' sections:

Borehole size	Minimum Mud Weight	Maximum Mud Weight
12.25''	11 ppg	13.5 ppg
8.5''	16.8 ppg	19.5 ppg

Table 1: Optimum Mud Weight Windows in KH-A

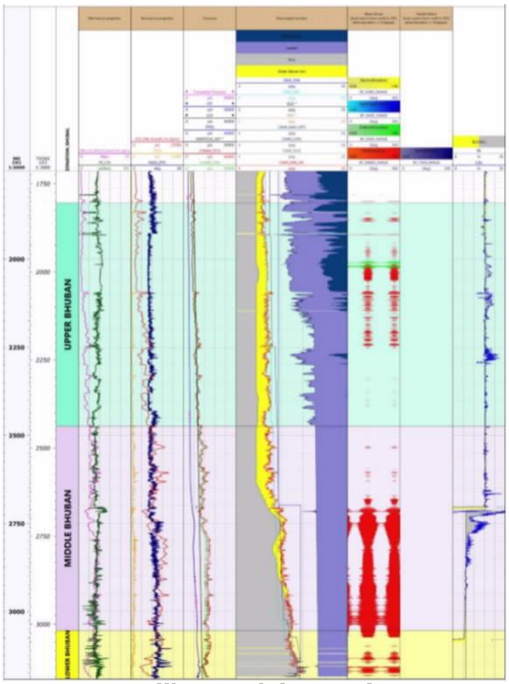

Figure 10: Wellbore Stability Analysis in KH-A

Sensitivity Analysis: Sensitivity analysis uses wellbore information (azimuth and deviation), WBS parameters (mud weight, mudcake coefficient), and MEM data (elastic properties, rock strength, pore pressure, stress) as input and perform WBS analysis with respect to a given depth and sensitivity analysis with respect to a specific input parameter. The Shear

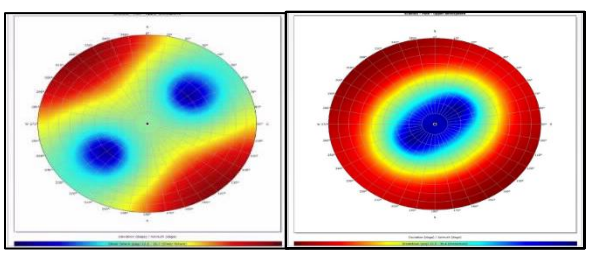

Figure 11: Sensitivity Analysis for shear failure (left) and breakdown (right) in KH-A

Failure Minimum Mud Weight (Breakout) Vs. Borehole Orientation plot shows breakout as a function of borehole orientation (azimuth and deviation), and the color shading indicates the wellbore damage mud weight. Plot in Fig.11 shows sensitivity analysis at the top of Lower Bhuban in KH-A. It depicts that minimum mud weight (13.5 ppg) will be required to avoid shear failure at top of Lower Bhuban, if well deviation is 40° and well azimuth is 50°N. Similar exercise can be carried out for Breakdown Mud Weight.

Conclusions

- Deeper part of Middle Bhuban and shallower part of Lower Bhuban are primarily overpressured because of uplifting and partly because of clay diagenesis (unloading mechanisms). Other overpressured zones are because of compaction disequilibrium. Modified Bowers method has been used to estimate type-2 overpressure.
- Using wireline pressure data, Velocity-effective stress relations have been developed for loading and unloading cases and parameters A, B and U determined.
- Estimated Pore pressure is fairly matching with recorded formation pressure data.
- Field specific correlations have been developed for static elastic parameters using triaxial lab data.
- The average direction of SH_{max} is 90° N in Upper Bhuban and Upper part of Middle Bhuban formation. It rotates to 50° N in Lower part of Middle Bhuban and Lower Bhuban formation.
- The MEMs have been subjected to well failure predictions in all the studied wells and the predicted failures have been matched with actual failures.
- Optimum mud weight windows and preferential azimuth to avoid shear failures have been provided in overpressured Middle Bhuban and Lower Bhuban formations.

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