Pore Pressure Estimation in Compressional Settings

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Keywords

Sonic Log, Normal Compaction Trend (NCT), Pore Pressure, Fracture Gradient

Summary

Pore pressure prediction is important for drilling safe and stable wells. Commonly sonic data or velocity estimates from seismic data is used in pore pressure predictions. For this purpose, a normal compaction trend (NCT) is established for hydrostatic pore pressure and deviation from NCT gives an estimate of overpressure or under pressure. In extensional settings, basin floor subsides with sediment loading. In case of rapid sedimentation overpressure develops when fluids from sediment is unable to escape. In a compressional settings on the other hand, for example in Tripura region, basin was shallowing while sediment loading was still going on. Therefore, establishing a normal compaction trend from sonic data is challenging. In our study, we establish multiple NCTs for pore pressure estimation. Measured pore pressure matches quite well with the estimated pore pressure from sonic data. Our new approach of computing NCTs in compressional basins can potentially help in pore pressure prediction from seismic data.

Introduction

Northward moving Indian plate and its subsequent collision with Eurasian plate led to the formation of the Himalayan fold-thrust belt that developed since ~55 Ma. The rate of shortening ranges between 19 and 22 mm/yr for this period of time [DeCelles et al 2001]. Much of the sedimentary sequence that accumulated along its northern margin of Indian plate from early Proterozoic through Paleocene time has been detached from the underlying basement in the form of large, south vergent thrust sheet. Tectonics of the area suggests that while the Indian plate was moving northward, the basin was shallowing and the sedimentation was taking place. It collided in the north with the Eurasian plate and in the east with the Burmese plate. Tipura fold belt in the east has undergone severe tectonic activities with series of folds and faults in the area.

Bhuvan formation of Miocene in Tripura region has been drilling targets for hydrocarbon accumulation. However, overpressure condition of the formation puts challenges in achieving drilling target depths. Well control and instability problems cause rising NPT and cost of the well.

In order to address the issue of borehole stability, it is important to make a geomechanical earth model of the area. The key starting step will be building a pore-pressure prediction model from sonic logs. Integrate it with the tectonic regime to predict fracture gradient and casing design

The pore pressure profile along the well is calculated based on the normal compaction method. In a post depositional compressional tectonics, unloading techniques are used for deriving normal compaction trend (NCT). However, in this area syn-depositional compression tectonics need to be taken into account.

Methodology

The first step in pore pressure estimation is to establish a normal compaction trend (NCT). During compaction process, formation water is expelled gradually from the sediments and porosity of the formation decreases. Therefore, density, velocity, and resistivity increase with depth. Usually, there are two approaches to determine NCT: one is based on sonic and the other based on resistivity data. We have used Bowers' method (Bowers, 1995) to fit NCT to sonic data as follows:

$$V_p = V_{ml} + A\,\sigma_e^B \qquad (1)$$

where V_p is the P-wave velocity, V_{ml} is the P-wave velocity at the mudline, σ_e is the effective vertical stress. *A* and *B* are constants obtained from regional calibration of velocity data.

In a normally compacted formation, pore pressure is hydrostatic and measured velocity follows the NCT. Deviation in measured velocity from NCT is a measure of overpressure or underpressure. Eaton's method (Eaton, 1975) is commonly used in pore-pressure (P_P) estimation.

$$P_p = \sigma_v - (\sigma_v - P_{hyd}) \times a \times \left(\frac{V_P^{log}}{V_P^{NCT}}\right)^n \quad (2)$$

where P_{hyd} is the hydrostatic pressure, σ_v is the vertical stress. Empirical parameters *a* and *n* are called Eaton factor and Eaton exponent, respectively. Usually a=1 and n=3.

Vertical stress in the above equation can be derived from the density log as follows:

$$\sigma_v = \int_0^z \rho(z) g \, dz, \quad (3)$$

where ρ is the formation bulk density, g is gravitational acceleration. In the absence of density log, one can use porosity depth relationship to estimate density as follows:

$$\phi(z) = \phi_0 \, e^{-C\,z}. \quad (4)$$

where ϕ_0 is the mudline porosity and C is a compaction coefficient. Further density can be estimated from porosity, matrix density (ρ_m) and fluid density (ρ_{fl}) using the following equation:

$$\rho_b = (1-\phi)\rho_m + \phi\rho_{fl}, \quad (5)$$

Furtheremore, fracture gradient (FG) is computed using Eaton's method (1969) using the following equation:

$$FG = \frac{\nu}{1-\nu}(\sigma_v - P_p) + P_p, \quad (6)$$

where ν is poisson's ratio of the formation.

Results and Discussions

Wavelet filtering of sonic data

Sonic data from Tripura area is shown in Figure 1. High frequency variation in the sonic data is filtered using wavelet transform based technique to smoothen the data. The original sonic data is shown in red color while the smoothened version of the data is overlain in black color (Figure 1).

Normal Compaction Trend

In order to build NCT, generally shales are identified from the logs and NCT is established using equation 1. Vertical stress profile is calculated from density log. For the section where density data is not available, we extrapolated the density log using porosity compaction /reduction technique (Equation 4 &5).

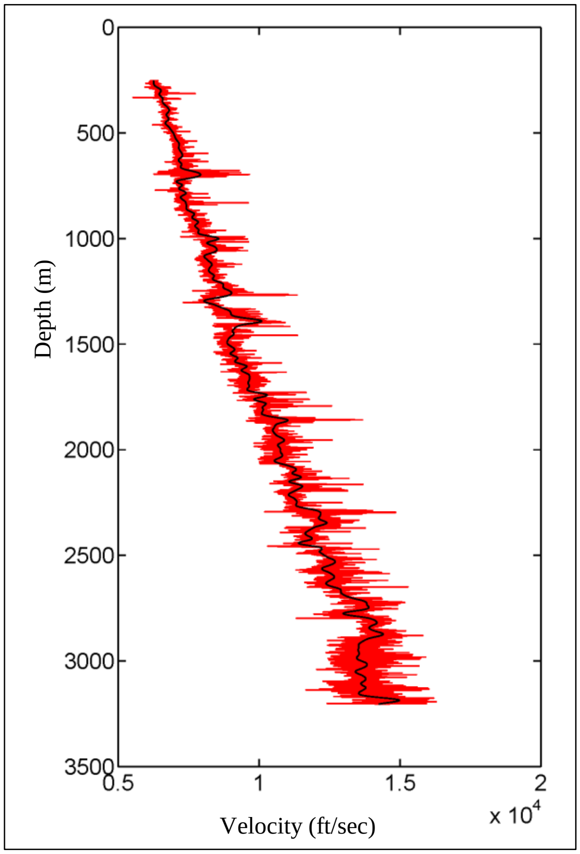

Figure 1: Velocity profile in black color represents filtered version of the sonic log data in red color.

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Smoothened sonic data is used in predicting pore pressure. We observe that in this area a single NCT is not enough to predict pore pressure. NCT which fits in the upper section estimates much higher overpressure for the lower section. If an NCT is based on older strata, it predicts underpressure for the upper section. This happens as the NCT takes into account only the stress from sediment loading. At least three different NCTs are built for the given sonic data (Figure 2). Lower Bhuvan has different NCT compared to that of Middle Bhuvan. Eaton's method then is used to compute pore pressure (Figure 3). Measured pore pressure is also plotted to compare it with the estimated pore pressure. Clearly, the measured pore pressure falls along the estimated pore pressure trend.

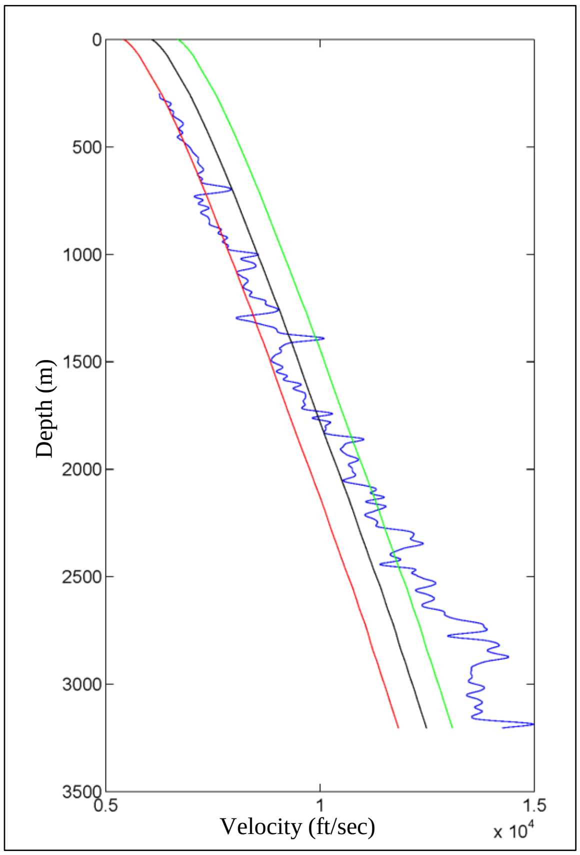

Figure 2: Three different Normal Compaction Trends overlain on velocity profile.

Fracture gradient is computed using Eaton's method. In the method, rock property is introduced in the form of Poisson's ratio (ν). The estimated values of fracture gradient is plotted in Figure 4. We have also plotted constant mudweight (MW) line on the same plot for easy reference. Upper and lower bounds of overburden gradient and hydrostatic pressure is plotted on Figure 4.

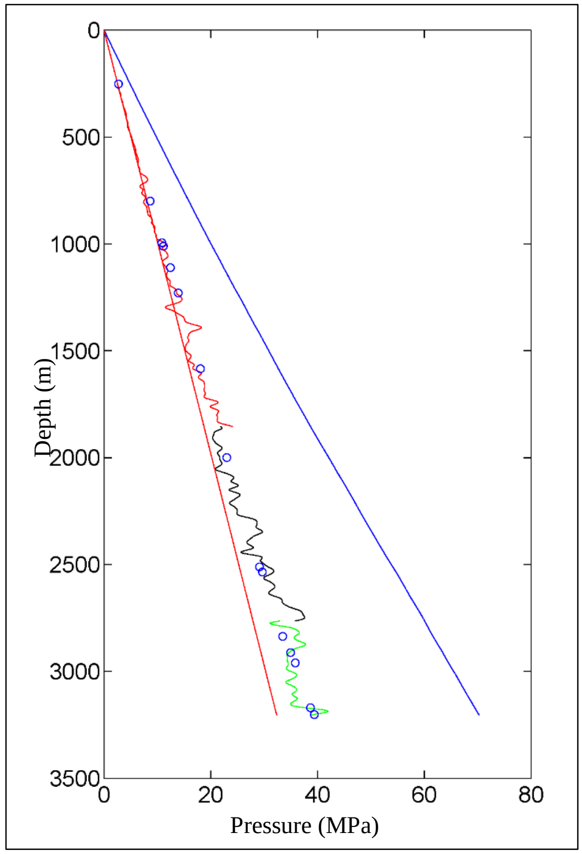

Figure 3: Estimated pore pressure using Eaton's method. Measured pore pressure data is plotted as open circles. Hydrostatic pressure is shown as red straight line and overburden is shown with blue color straight line.

Conclusions

Pore pressure prediction in compressional settings, particularly in Himalayan region requires a different strategy than those established for extensional settings. In particular, syn-depositional compressional tectonics requires multiple compaction trends that could be bounded by stratigraphy of the area. Study from sonic data from Tripura region suggests that an

NCT which is suitable for younger formation may yield much higher overpressure in the older formation while an NCT established for older formation may show underpressure in the younger formation. Pore pressure prediction based on single well multiple normal compaction trends includes tectonics and geology of the area. This model can be applied to other wells in the region for better understanding of the geomechanical earth model and integrating with seismic data which can potentially help in drilling deeper targets.

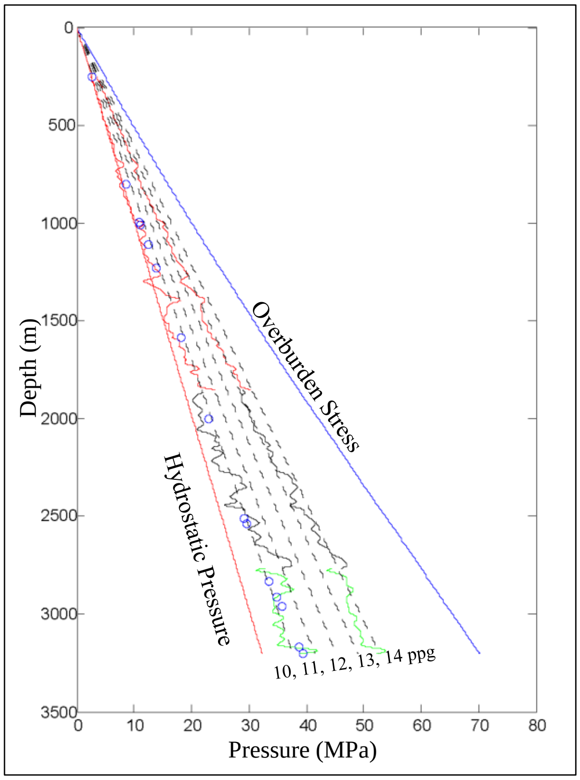

Figure 4: Estimated pore pressure, fracture gradient using Eaton's method along with constant mud weight lines are plotted on the same graph. Measured pore pressure data is plotted as open circles. Hydrostatic pressure is shown as red straight line and overburden is shown with blue color straight line.

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Acknowledgements

The work was performed at RGIPT with support from the institute research fund. We are thankful to ONGC for providing edited version of the real dataset for performing the analysis.