Estimation of Eaton’s Exponent and Tectonic Strain for Horizontal Stress Magnitude in Upper Assam Basin, India

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Elastic properties, Horizontal Stress, Tectonic Strain, Pore Pressure, Eaton, Blanton-Olson

Summary

Horizontal stress profiles play an important role in the design of hydraulic fracturing and the determination of wellbore stability. The use of logs has become the industry standard for determining the stress profile in the reservoir. By employing such services as sonic and density logging, reservoir properties such as Poisson’s ratio, overburden and pore pressure may be determined which are key parameters in calculating minimum horizontal stress profiles. We have estimated the Eaton’s exponent as 1 applicable for upper Assam for pore pressure prediction in two wells in normal and thrusted stress regime validated with MDT data. Further, using Blanton-Olson model we have calculated the strain value of -0.0034 in well located in normal faulted regime and +0.002414 for well in reverse faulted regime utilizing static Young’s Modulus and estimated minimum horizontal stress in each case and calibrated with known LOT data.

Introduction

Pore Pressure prediction and stress profiles are important parameters for (1)well planning, materials and costs estimates for construction of a safe, modern well including logistics, operations planning and procedural guidelines, and (2) prospect definition, financial risk assessment, overall project viability and basin exploration.

Being a young tectonically active belt rich in hydrocarbon resources wellbore stability becomes a major issue in exploration and production. Here we have estimated pore pressure (PP), vertical stress magnitude (S_v) and minimum horizontal stress magnitude (S_h) from two wells located in the tectonically active upper Assam basin.

Geological framework

The Assam province is divided into four tectonic regions namely the eastern Himalayan fold and thrust belt, the Mishmi Hills uplift, the Assam-Arakan thrust belt including the Naga thrust or Schuppen Belt and the upper Assam foreland basin. The Assam-Arakan thrust belt is the western edge of Indo-Burman Ranges developed due to the collision of Indian plate and Myanmar microplate (*Raoof et al*., 2017). The NW margin of this fold-thrust belt is known as Naga thrust. The Assam Shelf lying between the main boundary thrust (MBT) and Naga Thrust area is comparatively free from thrust tectonics and depicting normal faulting reaching down to basement. The two well locations are shown in Figure 1, along with the various thrust belts acting on and around them.

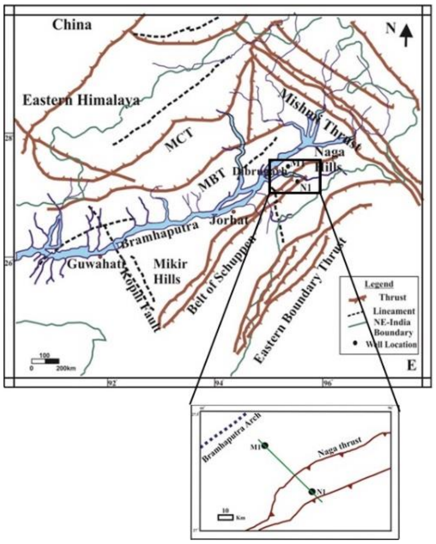

Figure 1: Geological setup of study area with well locations (after Nandy, 2000)

One of two wells namely, M1 is located in the Assam shelf region of normal faulting zone penetrates geological formations from top Alluvial through Dhekiajuli, Girujan, Tipam, Barail, Kopili, Sylhet, Langpur to the granitic basement. While the second well, N1 crosses through Girujan Suprathrust, Tipam Suprathrust, Argillaceous Barail Suprathrust and then reaches Naga Thrust. Two numbers of seismic sections traversing wells M1 and N1 are displayed in Figure 2a and b respectively. Figure 2a is showing the well location (M1) with geological horizons in normal faulted region. Similarly Figure 2b displays well N1 with Margherita Thrust and geological horizons. This paper will show the estimation of Eaton's exponent (*Eaton*, 1972) for normal and thrust faulted regime in upper Assam.

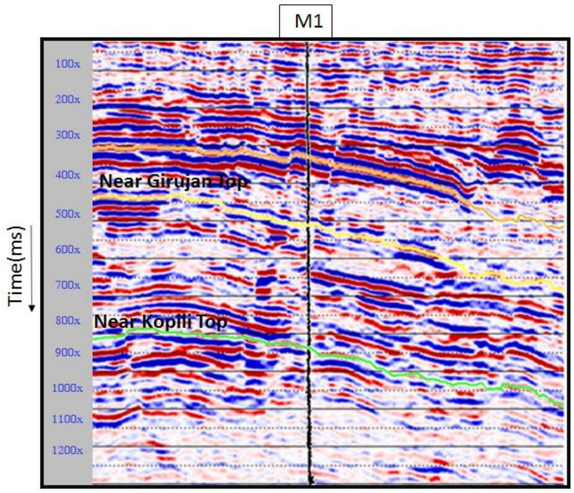

Fig 2a: Seismic section of well M1

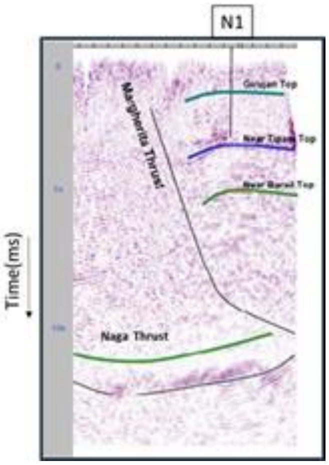

Fig 2b: Seismic section of well N1

Theory and Method

Conventional well logs namely gamma ray, sonic velocity, shear velocity and density are used as raw data for estimation of PP and S_v. Caliper log and bit size are calibrated to remove possible washout zones. Figure 3 shows the workflow followed for estimation of the uniaxial horizontal stress from well log data.

Sand points in log are identified using gamma ray log and removed for compaction trend estimation.

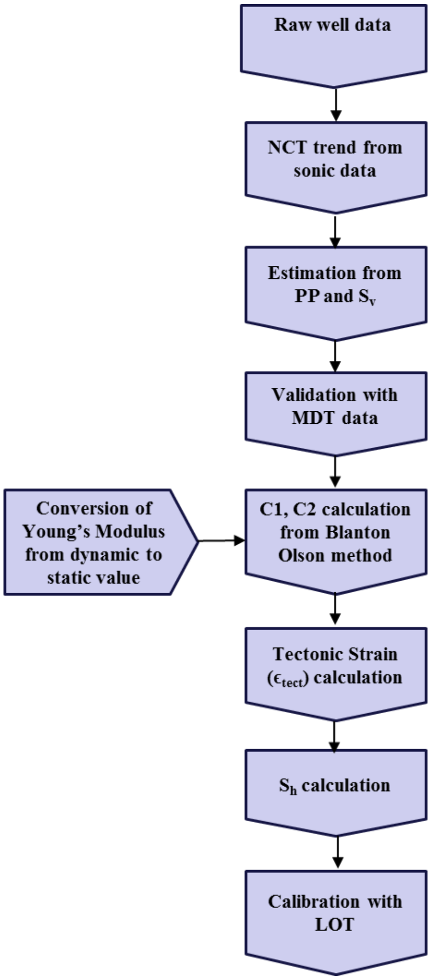

Figure 3: Flowchart for stress estimation

Normal compaction trend is drawn considering shale points for both wells (Figure 4a and b). The normal compaction trend is established using this shale compaction curve and the relationship is obtained as follows:

For M1

$$\Delta t_n = 157.36e^{-0.00025*depth}$$

For N1

$$\Delta t_n = 125.02e^{-0.0003*depth}$$

where Δt_n = normalized sonic travel time.

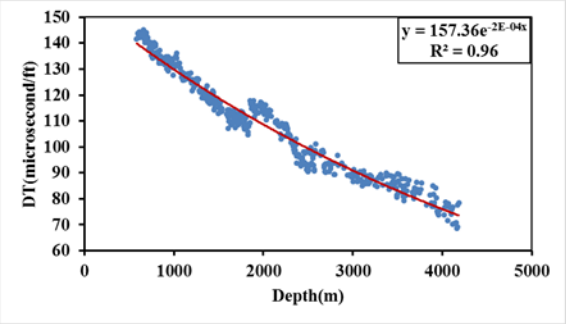

Fig 4a: NCT trend for well M1

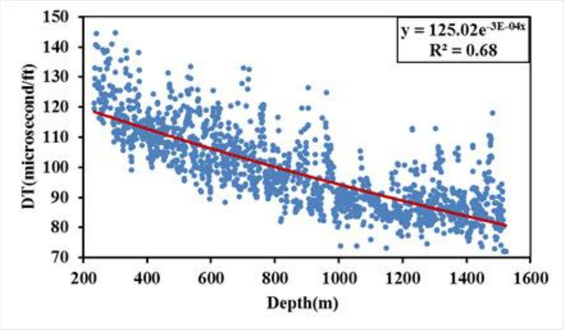

Fig 4b: NCT trend for well N1

Vertical stress (S_v) is calculated using bulk density of the rock which is force per unit area applied by load of rock above the point of measurement. The required equation given by *Plumb et al*.(1991) is

$$S_v = \int_0^z \rho(z) g dz$$

where z = depth at point of measurement,

ρ (z) = bulk density of the rock which is function of the depth.

g = acceleration due to gravity

Pore pressure is calculated using the following formula given by Eaton (1972)

$$PP = S_v - (S_v - P_h) * (\Delta tn / \Delta t)^x$$

where Ph = hydrostatic pressure taken as 10MPa/km

Δt = sonic transit time

x = Eaton's exponent

The PP has been calculated using Eaton's sonic equation with varying exponents of 1, 2 and 3 (Figure 5a and b) and calibrated with measured pressure obtained from Modular Dynamic Tester (MDT) and mud weight (MW) used while drilling. The results thus obtained are plotted here.

Estimated PP is noticed to match closely with Eaton's exponent 1.

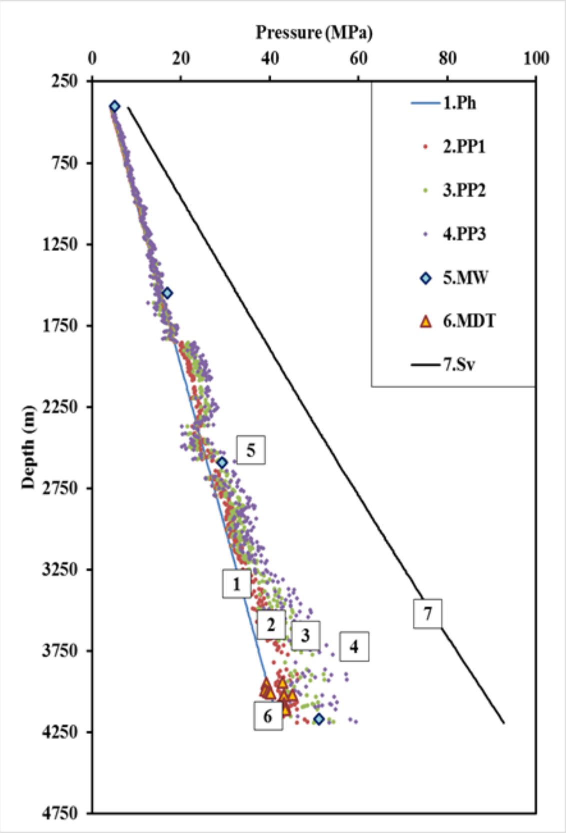

Fig 5a: PP^1, PP^2 and PP^3 pore pressure estimated with varying Eaton's exponent with hydrostatic pressure (Ph), mud weight (MW), Modular Dynamic Tester (MDT), S_v for well M1.

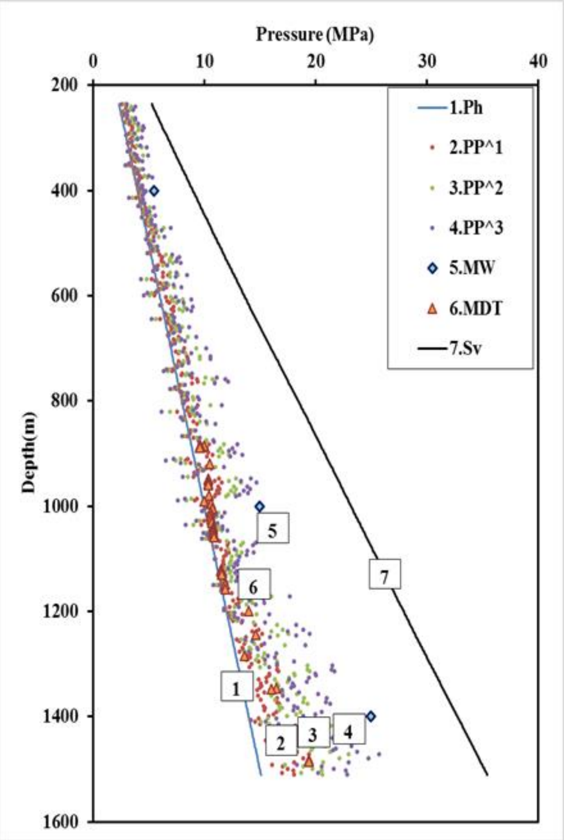

Fig 5b: PP^1,PP^2 and PP^3 pore pressure with varying Eaton's exponent, P_h, hydrostatic pressure, mud weight (MW), Modular dynamic Tester (MDT), S_v for well N1.

Therefore PP estimation will be carried out using exponent 1 for upper Assam basin. A little high PP gradient of 12.5 MPa is detected in M1 well at depth 3250m. The high PP prevails in Kopili through Langpar formation ageing Eocene to Late Paleocene. The observed abnormal pore pressure gradient ranges from 12.0 to 12.5 MPa/km. The magnitude of S_v has a gradient from 22.1 in normal region to 23.8 MPa/km in thrusted region.

Conventional methods assume that rocks behave purely elastically and that overburden and pore pressure are the sole contributors to rock stress. However in reality rocks may behave inelastically for significant periods in their history with material properties which vary with time depending on consolidation and diagenesis (*Blanton and Olson, 1999*).

This approach determines uniaxial tectonic strains assuming porous medium and uses static Young's Modulus, Poisson's Ratio, S_v, PP, leak off test (LOT).

Blanton and Olson (1999) developed new constants which involved the properties of the rock Young's modulus and Poisson's ratio for each incremental measurement.

$$C_1 = \frac{Y}{1-\mu}$$

$$C_2 = \frac{\mu Sv+(1-2\mu)PP}{1-\mu}$$

Where C_1, C_2 = Blanton Olson constants (*Blanton and Olson*, 1999)
μ = Poisson's ratio
Y= Static Young's Modulus

The minimum horizontal stress equation is given by (*Blanton and Olson*, 1999):

$$S_h = \mu C_1 \epsilon_{tect} + C_2$$

$$\epsilon_{tect} = \frac{Sh' - C2'}{\mu C1'}$$

where S_h= minimum horizontal stress
ϵ_{tect} = tectonic strain

The primes in the last equation indicate that these terms are associated with the particular depth at which the minimum horizontal stress has been measured with testing data. Since this strain corrected method accounts for the variation in rock properties through the section, we can calibrate it using closure pressure such as: Leak off Test (LOT) from either shale or sandstones and still get a good overall match (*Singha and Chatterjee*, 2014).

Static values of elastic constants are based on the measurement of deformation induced in a material by a known force unlike the dynamic constants which involve measure of ultrasonic body wave velocities. Static Young's modulus (Y_{stat}) is calculated from dynamic Young's modulus (Y_{dyn}) using the following relation: (*Wang*, 2000)

$$Y_{stat} = 0.4142 * Y_{dyn} - 1.0593$$

Results and Discussions

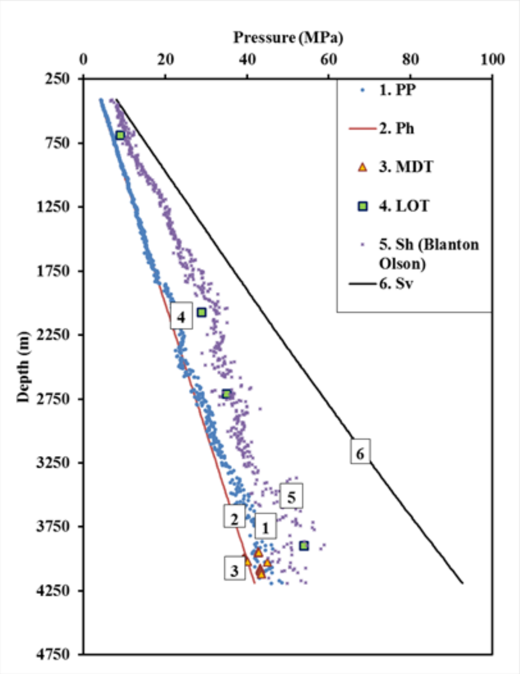

Figure 6a: PP, P_h, MDT, LOT, S_v with minimum horizontal stress from Blanton and Olson (1999) method from M1

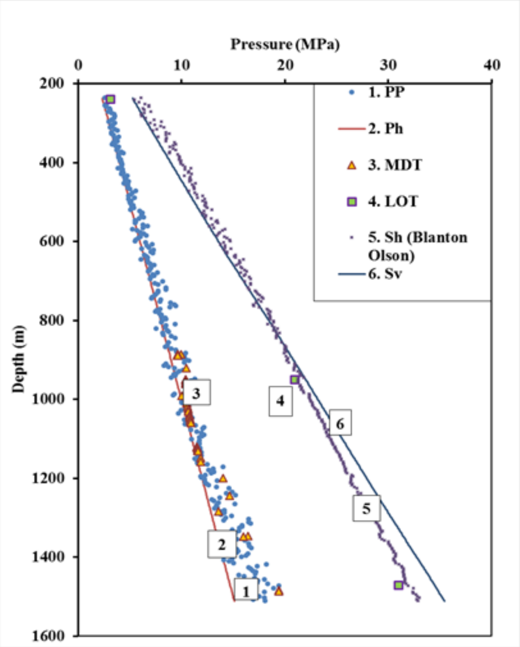

Figure 6b: PP, P_h, MDT, LOT, S_v with minimum horizontal stress from Blanton and Olson (1999) method from N1

Horizontal uniaxial tectonic strain is found to vary from -0.0034 in thrust faulting to 0.002414 Normal faulting regime. The positive value indicates compressive regime whereas negative value indicates extensile/normal faulting regime.

Figure 6a and b illustrates hydrostatic pressure, PP, MDT, S_v and estimated S_h with LOT for wells M1 and N1 respectively. For both wells the estimated minimum horizontal stress matches fairly well with other known LOT points. Figure 5a shows a lesser value of S_h as compared to S_v with S_h/S_v ratio averaging at about 0.65 suggesting clearly that the well lies in a normal faulted regime. On the other hand figure 5b indicates more value of S_h than the value of S_v with the ratio of S_h/S_v averaging at 1.01 suggesting thrust faulting regime at N1 well location (*Zoback et al.*, 2003). The tectonic strain obtained in thrust faulting regime of upper Assam matches well with the thrust faulting regime of Lost Hill Well in California (*Blanton and Olson*, 1999).

Well	**M1**	**N1**
LOT	9 MPa	21 MPa
C1	229.269	4968.61
C2	12.524	17.0378
Poisson’s ratio	0.44	0.35
ϵ_{tec}	-0.0034	0.002414

Table 1: Lists the LOT, constants (C1, C2), tectonic strain (ϵ_{tec}) at well location in upper Assam.

Conclusions

Eaton’s exponent of 1 has been found to match fairly well in both the wells for pore pressure prediction with MDT and MW data and so can be further used in other wells of the upper Assam region. The exponent holds true for normal as well as thrust faulting regime.

Blanton and Olson parameters provides a good model to calculate horizontal strain at well locations and so can be used for estimation of minimum horizontal stress in upper Assam basin.

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