Pore Pressure Prediction and analysis of High Pressure Formation using wire line logs: A case study of Tripura-Cachar fold belt of Assam Arakan basin

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Keywords

HP-high pressure, PP-pore pressure, OBG-overburden gradient, FG-fracture gradient, MDT-modular dynamic tester, LOT-leak off test, PPG-pound per gallon,

Summary

In complex and unpredictable geological formations safe and economical drilling for exploration of hydrocarbons may prove to be difficult at times. This is true if the in-situ formation pressures are unknown or have sudden high pressure zones. Therefore, an accurate knowledge of formation pressure is essential to reduce the well complications. This study studies and predicts the in- situ state of pore pressure distribution in a field of Tripura-Cachar area. The Tripura-Cachar fold belt of Assam Arakan basin is well known for high pressure in NE of India. The exploration activities have been confined mostly to the shallower prospects, whereas deeper prospects are still unexplored mainly because of abnormal high pressure. High pressure creates unwanted problems in successful drilling, testing and completion of a well. In addition to difficulties in designing of proper mud and casing policy, high pressure environment may also create problems in recording of OH log data from the logging tools, as these tools are designed to operate within a fixed range of temperature and pressure values. In the present study, a continuous pore pressure gradient, fracture gradient, over burden gradient and temperature gradient data have been generated through well logs and Bottom Hole Temperature (BHT) data for over 11 wells of Agartala Dome field of Tripura Asset. Out of the 11 studied wells, four wells have been penetrated in the Lower Bhuban formation. Basic log data of Gamma Ray (GR), Density (RHOB) and Sonic Travel Time (DT) have been used for computing pore pressure, fracture pressure and over burden pressure gradients. The computed pore pressure gradient was validated with formation pressure data such as MDT etc. whereas, Fracture Gradient (FG) was validated with LOT (Leak-Off Test) data. The estimated pore pressure gradient was used for generating map for high pressure distribution over the field. Through the map, High Pressure (HP) trend was analysed to predict HP Formation in Agartala Dome field.

Introduction

Prior knowledge of pore pressure or formation pressure is essential for successful drilling and completion of a well. Wire-line logging tool is also prone to get stuck in high pressure well than in a normal pressure well. Therefore, accurate knowledge of formation pressure helps in designing proper mud weight and casing policy which may be helpful in prevention of kicks, formation damage, circulation loss, borehole collapse and even blowout. The knowledge of predrill formation pressure is also the more essential in case where log data is not available. Predrill pore-pressure prediction can also be obtained from seismic interval velocity and validating with the MDT pressure points and log derived results.

Methodology

Hydrostatic Pressure at a depth is the pressure exerted by the weight of a static column of fluid from surface to the desired depth.

$$P_{hyd} = h\rho_f g \quad \ldots\ldots\ldots\ldots (1)$$

Where, h = height of fluid column, ρ_f = Density of fluid and g = Acceleration due to gravity.

Overburden Pressure is a pressure exerted by the weight of overlying sediments, including the weight of the pore fluids.

$$OBG = \int (\rho g)dh \quad \ldots\ldots\ldots\ldots (2)$$

Here ρ is the bulk density.

Pore pressure is defined as the pressure exerted by the fluid contained in the pore space. Pore pressure can be categorized as i) normal, ii) subnormal and iii) abnormal pressure. As total over burden stress (OBG) is jointly supported by the pore fluid and the rock matrix (Terzaghi's Relationship, 1943), therefore,
Overburden Pressure (OBG) = Pore pressure (PP) + Effective Vertical Stress (σ_{ev})

$$\text{Or, } PP = OBG - \sigma_{ev} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, effective vertical stress is the stress applied to the rock matrix.
Fracture Pressure is pressure required to initiate a fracture in the formation. It is also known as fracture initialization pressure (FIP), fracture opening pressure (FOP) or rupture pressure

a) Selection Of Shale Point: Natural Gamma Ray (GR) log (with the help of other logs) has been used to discriminate shale and the same was projected on sonic transit time (DT) curve to generate shale points.

b) Density profile: As density log is required in the entire interval of the well under study to determine over burden stress, synthetic RHOB log (ρ) was generated from DT by Gardner method (Eq.4). In the interval where density (RHOB) log was not recorded. Miller method has been used to calculate RHOB from MSL to mudline where DT is not recorded.

$$\rho = A(10^6/DT)^B \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, ρ is in g/cc and DT is in us/ft; A and B are constants and have default value 0.23 and 0.25 respectively.
These synthetic RHOB logs were then merged with the original wireline density log to generate density curve for entire interval of the well.

c) Overburden Gradient (OBG): By integreting density log over the entire interval of the well, Over Burden Gradient (OBG) was obtained (Eq. 2).

d) Normal Compaction Trend (NCT): Once shale points are generated on DT, approprite filter has been applied on these shale points in order to smoothen the shale discriminated DT. Then Normal Compaction Trend (NCT) was generated to know the normal trend of the accoustic compressional slowness using Miller method.

e) Pore Pressure Gradient (PPG): By using Eaton's method pore pressure gradient was estimated by using following equation:

$$PP = OBG - (OBG - PP_n)(DT_n/DT)^m \quad \ldots\ldots\ldots\ldots (5)$$

Where,
PP = Pore Pressure Gradient (PPG)
OBG = Overburden Gradient (PPG)
PP_n= Normal Pore Pressure Gradient (PPG)
DT = Observed Interval Transit Time, (usec/ft)
DT_n = Normal Interval Transit Time, (usec/ft)
m = Eaton Exponent.

f) Fracture Gradient (FG): Fracture Gradient (FG) was determined by Mathew & Kelly (MK) method.

$$FG = PP+(OBG-PP)Ki \quad \ldots\ldots\ldots\ldots (6)$$

Where,
Ki = Matrix Stress Coefficient.
The estimated pore pressure and fracture pressure were compared with mud data and calibrated with MDT and LOT data.
A comparison were made between the estimated pressure gradients and and 'D'-exponent data recorded during drilling.

Results and Discussion

Pore Pressure Prediction from conventional well logs:

Well log composites showing pressure gradient data along with log curves have been generated for all the key wells with the adoption of above mentioned methodology. An example is shown below for the Well-A:
In the present well **(Fig.:1),** the pore pressure curve shows normal pressure regime from surface to

3232m, transitional pressure from 3232m to 3696m and high pressure regime from 3696m to bottom depth 4193m. The transitional Pore Pressure Gradient (PPG) 9.22ppg is observed at depth 3232m and corresponding FG and OBG values are 17.15ppg and 19.78ppg respectively.The high pore pressure gradient 14.76ppg is observed at 3696m and corresponding FG and OBG values are 18.75ppg and 20.07ppg respectively. The generated pore pressure curve is matching with DST pressure points.

The scales of individual curves in well composite **(Fig. 1&2)** are as follows: Track-1: CALI- 6-66 Inch, BS-6-66 Inch, GR-0-200 GAPI.
Track-2: Resistivity Log- 0.2-2000 Ohmm.
Track-3: DT- 240-40 us/ft, NPHI-0.54—0.06 v/v, RHOB- 1.8-2.8 gm/cm3.
Track-4: DT- 240-40 us/ft, SHPT-240-40 us/ft. Track-5: BHT-50-350 F, CSG-2-22 Inch, MDT-2-22 ppg, MW-2-22 ppg, PP-2-22 ppg, OBG- 2-22 ppg, FG-2-22 ppg.
Track-6: psi/ft.

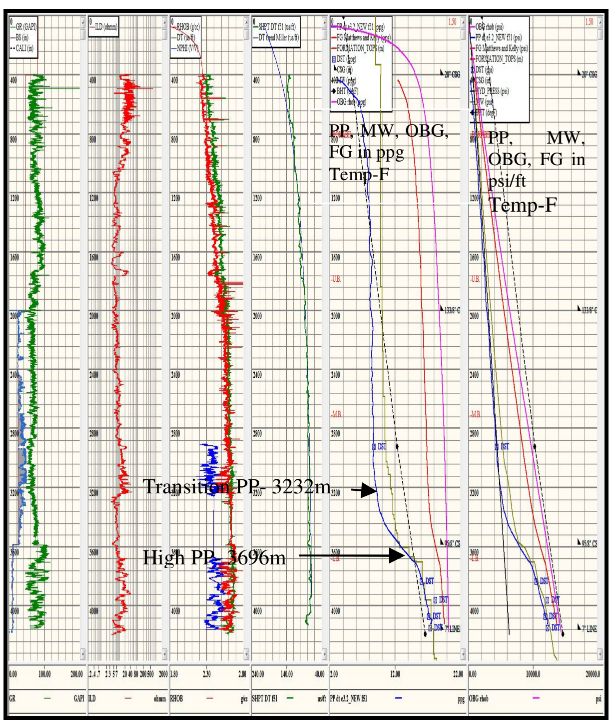

Fig.-1: Well-A. Pore pressure, Fracture, Overburden and Temperature gradients plot from log data

Pore Pressure Prediction from Seismic Interval Velocity Data:

For predrill pore-pressure prediction, interval velocity obtained from processed seismic data is used to predict the pore pressure, fracture gradient and over burden gradient through the available software. The interval velocity data has been used instead of sonic data (DT) for the computation of normal compaction trend. The generated results in both ways have been matched with the MDT pressure points. The interval velocity data is always be available in deeper stratigraphy than the recorded log data and can be used for predrill pore pressure prediction. The quality of the generated output has to be matched with the log derived results and MDT pressure points.

The results generated from interval velocity are shown in (**Fig.:2).** The similar scales have been used for curve display like track-5.

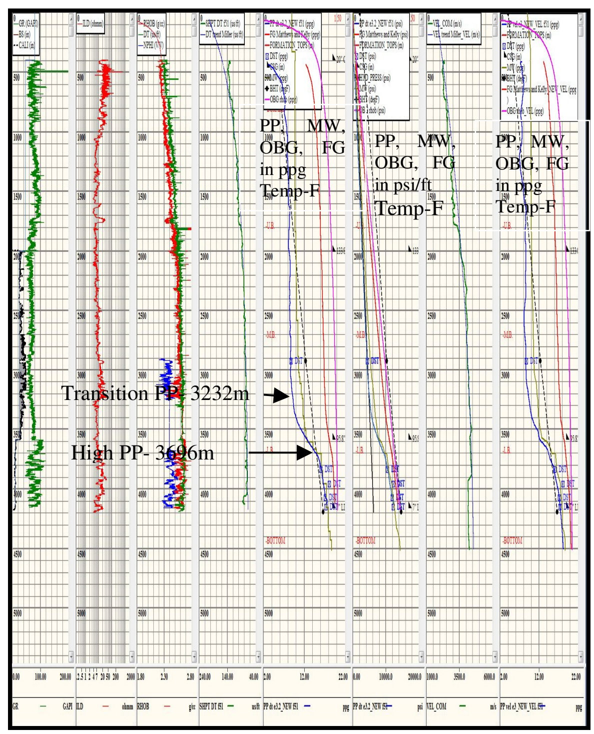

Fig.2: **Well-A**. Pore pressure, Fracture, Overburden and Temperature gradients plot from logs data and interval velocity data

Histogram Analysis

A W-E profiles of pressure distribution at Transitional pressure start point, high pressure start point and PP~10,000 psi point of the wells have been prepared across the field. Pore pressure is increasing from West to East direction of the field at all levels **(Fig.:3).**

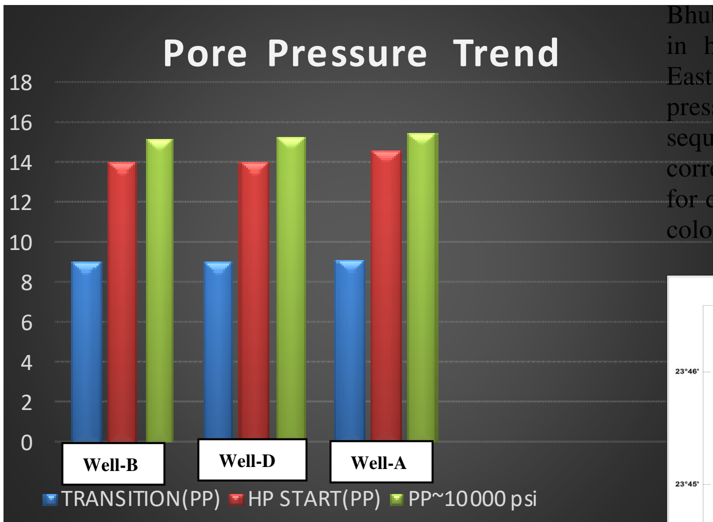

Fig.3: Pore pressure distribution from west to east at Transition, HP start point and PP~10000 psi point.

Generation of Maps and Analysis

The generated outputs from logs were used to generate maps and to establish a regional trend of pressure. Well-wise pore pressure gradient, fracture gradient, overburden gradient were calculated and from the pore pressure curve PP maxima against transition pressure zone, high pressure zone were estimated. The depth corresponding to these values were noted to get the exact location of maximum pressure in the well. In case of well with normal pressure, the maximum pressure recorded in the well and the corresponding depth was collected. As per industry standards, pressure >10000 psi considered as the criteria for selection of high pressure wells. Hence, the depth at which the wells encountered 10000 psi was noted. These data have been used to generate maps.

High Pressure Map

The high pressure map brings out variation in the depth of occurrence of high pressure across the area. It shows a well-wise general trend of depth of occurrence of pressure. The four wells out of total 11 studied wells have been penetrated the Lower Bhuban Formation. In the high pressure map, the rise in high pressure is observed in the direction of Eastern part of Well-D. In all the four wells, high pressures are found in the same stratigraphic sequence of Lower Bhuban Formation. In the map, corresponding depth of high pressure start is taken for depth contouring and corresponding pressures for color **(Fig.:4).**

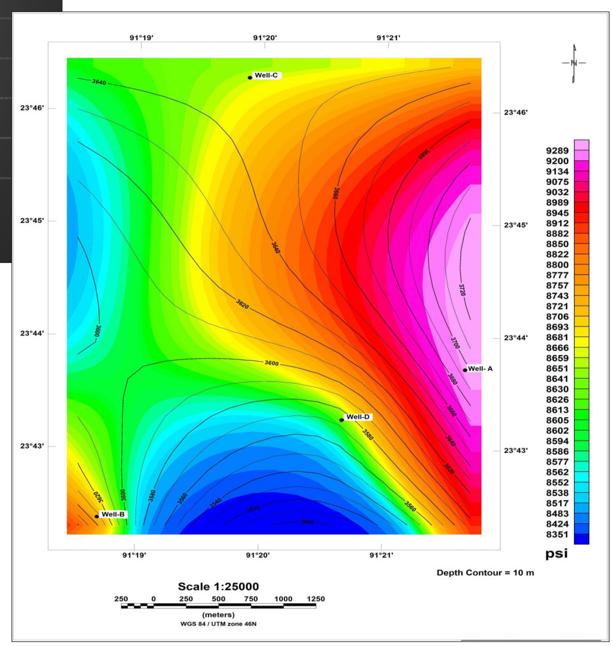

Fig. 4: High Pressure Map

Conclusions and recommendations

- Normal pressure regime is observed from surface to mid-Middle Bhuban Formation.
- Transitional pressure regime is noticed from mid-Middle Bhuban Formation to top of Lower Bhuban Formation.

- High pressure regime is noticed from top of Lower Bhuban Formation to drilled depth (approx. 4000m).
- The average pore pressure gradient in psi/ft. for the studied deep wells in Middle Bhuban and Lower Bhuban formations are :
  Transitional pressure gradient: 0.61 psi/ft. (Middle Bhuban Formation)
  High pressure gradient: 0.83 psi/ft. (Lower Bhuban Formation)
- Temperature gradient indicates rise in gradient against the over pressure section. The increase in temperature may increase the pore fluid volume which causes overpressure in the formations.

Based on this study, a safe mud window may be used in between pore pressure and fracture gradients for drilling of new wells. From the results of this study, mud and casing policies can be designed before drilling the well. For predrill pore-pressure prediction, interval velocity obtained from processed seismic data might be used to predict the pore pressure, fracture gradient and over burden gradient with the best match to MDT and log derived results.

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Acknowledgements

The authors are thankful to ONGC management for granting permission to publish this paper. The authors are grateful to ED-HOI-KDMIPE, DR. D.N Singh for his encouragement. The views expressed in this paper are of the authors only and may not necessarily be of the organization to which they belong.