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Predicting and Characterizing Pore Pressure of a Selected Field in the Niger Delta Basin, Nigeria

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ABSTRACT: Predicting pore pressure is critical in every exploration venture because it prompts safe drilling, fluid design, casing emplacements, improved wellbore dependability, and water driven cracking enhancement. Hence, the objective of this paper was to predict and evaluate the pore pressure characteristics of a selected field in the Niger Delta Basin of Nigeria using appropriate standard methods. The results of the 1D pore pressure model from the Eaton and Bower's sonic techniques revealed that the deviation from Normal Compaction Trend started at about 8350 ft as a result of overpressure. The determined break angle from the Fracture gradient formular, utilizing the Effective Stress Ratio (ESR), Overburden Pressure (OVP) and the anticipated Pore Pressure (PP) was estimated to be between 0.65 psi/ft and 0.725 psi/ft. Due to the use of overbalanced drilling in the Niger-Delta, wellbore pressure should be higher than the Hydrostatic pressure, but not as high as the fracture pressure. Therefore, the safe drilling window should likely be from 0.613 psi/ft to 0.645 psi/ft for the study area.

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The choice to launch a project is impacted by numerous critical factors, such as the state of the economy, profitability, and the capacity to generate a profit. Choosing target prospects, drilling logistics, and well design wisely will help them grow over time when seeking for and using different forms of oil and gas. The accessibility of precise pore pressure data is one of the most crucial aspects of these elements. To keep the pressure in the wellbore constant, precise measurement of pore pressure is essential. This is due to the fact that it plays a crucial role in developing the geomechanical model, which in turn promotes better drilling safety, fluid design, casing placement, and wellbore stability. Failure to control these extremely high pressures could result in a blowout, an uncontrollable flow of formation fluids. The operator runs the risk of suffering huge financial losses, ecological harm, oil reserve depletion, and the introduction of hazardous working conditions for employees. Predictions regarding overpressure were made using empirical data analysis based on seismic data and well logs (Eaton 1972; Bower 2002). Based on Eaton's work on the dc-exponent parameter (also known as formation resistivity) and the duration of a sonic pulse, this empirical formula for pore pressure is derived. Bower, in contrast, determined vertical effective stress using sonic velocity. Subtract the overburden tension to get the pore pressure. Drilling data, acoustic logs, and pressure measurements were used to make overpressure estimates in several sections of the Niger Delta Basin (Daukoru, 1975). This study is aimed at creating a model that predicts the pore pressure characteristics of a selected Field in the Niger Delta using standard methods.

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MATERIALS AND METHODS

The following materials were used in predicting and characterizing the overpressure in the study area.

The Location of the study Area: Field KK (Fig. 1) is a pseudo name of the Field; it is located around the shallow offshore region of the Niger Delta basin. Specific locations of the field have been withheld as a condition for obtaining the data for the course of this work.

Geology of the Niger Delta Basin: The Niger Delta Basin is a structure that is the failing arm of the triple junction where Regressive offlap sediments began to form in the late Jurassic period (Whiteman, 1982). The separation of the South American and African plates as a result of extensional fracture caused this. Located in the Gulf of Guinea on Africa's western coast is the Niger Delta. Its 300,000 sq. km. of surface area is filled with sediment that fills 500,000 cu. km (Kulke, 1995). Depocenter sediments range in thickness from 10 to 12 kilometers (Kaplan *et al.* 1994). The delta may be considered as an integrated oil system according to some scholars, such as Kulke (1995) and Ekweozor and Daukoru (1995).

Fig 1*:* Location map of the study area.

Suites of wireline logs: Caliper, Gamma ray, resistivity, sonic and density logs from existing wells were employed in lithology delineation while Compressional velocity and shear velocity were deduced using their corresponding sonic logs. Volume of shale (Vshale) was estimated using the Gamma ray log as input. Pressure data (Repeated Formation Test) was used to construct the pressure gradient and display the pressure trend in this study; Well information such as the Fluid fill and lithology, Structural and Stratigraphic models of the area were input parameters in building the Pressure model.

Rokdoc Software: It can precisely read direct and indirect (mud weight) pressure data, in addition to creating and calibrating pore pressure models. With this function, viewing lab data, image logs, and drilling data is a breeze. By combining static and dynamic information, you may uncover stress patterns and gain a better understanding of the historical performance of drilling and production.

Estimation of pore pressure: In order to determine the pore pressure, Eaton used information from the well logs, including the formation resistivity, sonic transient time, and dc-exponent, to formulate an empirical equation presented in Equation 1.

$$P_p = \frac{S - \sigma_{eff}}{\alpha} \quad (1)$$

The variables $\boldsymbol{P_p}$, $\boldsymbol{S}$, σ, eff, and α represent several parameters related to the pore pressure, overburden stress, vertical effective stress, and Biot effective stress coefficient, respectively.

As the volume of the filled fluid changes, it is proportional to Biot's coefficient. When the fluid is allowed to exit the rock, the volume-to-porosity ratio changes. It is commonly believed that α=1 when geopressure is being studied.

Assuming that PP is the Pore Pressure Gradient in ppg, OBG is the Overburden Gradient in ppg, PPN is the Normal Pore Pressure Gradient in ppg, Ro is the Observed Resistivity in ohms-m, and RN is the Normal Resistivity in ohms-m, we can use the formula PP = OBG - (OBG - PPN) (Ro/RN) x to get the Eaton Exponent, which is 1.2.

Determination of Vertical Effective stress: To determine the vertical effective stress, Bower's approach was used with the relationship between effective stress and sonic velocity presented in Equation 2.

$$\frac{V1}{4} = V_o + A_{\sigma^B} \quad (2)$$

The parameters A and B are determined by measuring the difference between the effective stress and the regional offset velocity. V represents the speed at a specific depth, VO is the speed at the surface (often 5000 ft/s), and π is the vertical effective stress.

From this empirical method, normal Compaction Trend was also deduced. Normal compaction Trend (NCT) was computed using shale velocity and volume of shale logs as inputs. The reciprocal formula was incorporated to calculate the NCT log presented in Equation 3

$$\frac{1}{V_P(Zml)} = \frac{1}{V_P matrix} - \left(\frac{1}{V_P matrix} - \frac{1}{V_P Top}\right) e^{-bZ_{ml}} \quad (3)$$

Where: $V_P(Zml)$ = velocity relative to mud-line depth reference; $V_P matrix = Velocity\ of\ th\ rock\ matrix = 3600 m/s$; $V_P Top = Velocity\ at\ the\ top\ of\ the\ formation = 1850 m/s$; $b = compaction\ coefficient = 0.00078$; $Z_{ml} = Mudline\ depth\ reference$

RESULTS AND DISCUSSION

Lithology Description: From the Gamma Ray log in Figure 2, it was deduced that the formation has series of sand and shale overlying each other. Also, the RFT information (Figure 2) showed a pressing factor pattern demonstrative of overpressure when plotted in the well section window.

Pore Pressure Prediction: The predicted pore pressure from the two techniques was consolidated and called Eaton-Bowers (displayed in green) as seen in figure 3. The deviation from Normal compaction trend started at about 8350 ft as a result of overpressure (Fig. 2 and 3).

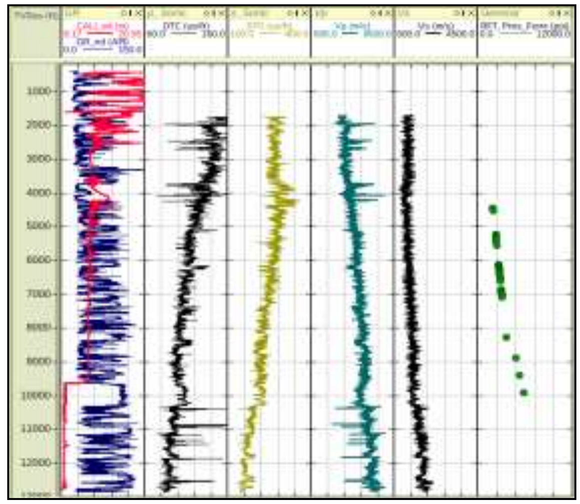

Fig 2: A section view showing gamma ray log of the formation with series of sand and shale overlying each other. The RFT pressure showed a deviation pattern of the normal compaction trend demonstrative of an overpressure.

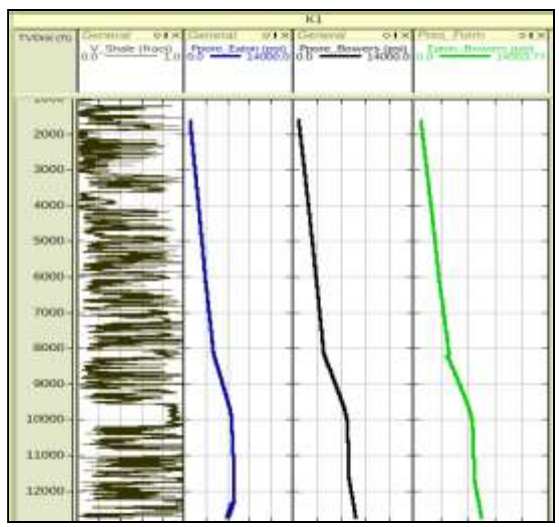

Fig 1: A Section View Showing the Volume of shale, Predicted Pore Pressure (Eaton), Predicted Pore Pressure (Bowers), and Predicted Pore Pressure.

The computed hydrostatic gradient and lithostatic gradient were plotted in Pressure vs Depth plot along with the predicted pore pressure (Figure 4). The deviation from Normal Compaction Trend also started at about 8350 ft as a result of overpressure.

Considering that overpressures might be brought about by various components like disequilibrium compaction, liquid extension (Swarbick, 1999). A cross plot of Velocity against Density was made to decide the wellspring of the overpressure (Figure 5).

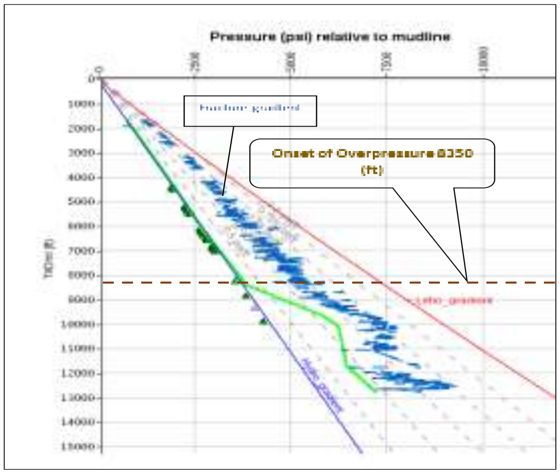

Fig Error! No text of specified style in document.**:** Total Vertical Depth versus Pressure Plot Showing the Lithostatic Gradient and the Hydrostatic Gradient and predicted onset of overpressure.

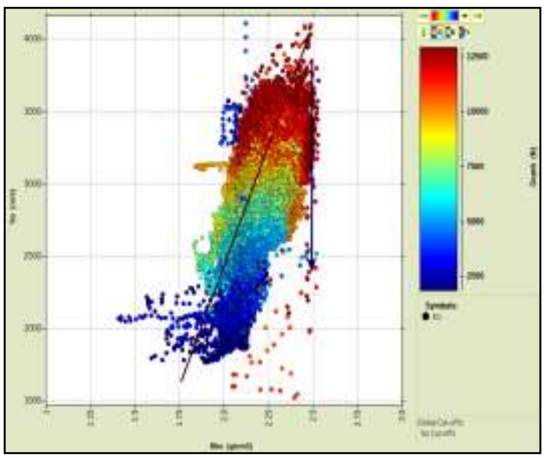

Fig 5: Density and sonic velocity cross-plot on the Study Area.From the loading limb, the green dots indicate just-right/normal pressure and brown dots indicate spots where it's too high.

Fracture Gradient (FG) determination: Fracture gradient which is the pressing factor in which a development breaks, was determined utilizing Effective Stress Ratio (ESR), Overburden Pressure (OVP) and the anticipated Pore Pressure (PP).

$$FG = ESR * (OVP - PP) + PP \quad (4)$$

The determined break angle is from 0.65 psi/ft and 0.725 psi/ft.

Due to the use of overbalanced drilling in the Niger-Delta, wellbore pressure should be higher than the Hydrostatic pressure, but not as high as the fracture pressure. Therefore, the drilling window range should be 0.613 psi/ft and 0.645 psi/ft

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Conclusions: The study on predicting and characterizing pore pressure using Eaton and Bowers empirical methods revealed that the onset of abnormal pressure is likely to begin at about 8350 ft. Hence, a safe drilling window would likely be from 0.613 psi/ft and 0.645 psi/ft. For a safe drill within the study area, a mud weight of about of 0.608 psi/ft will be recommended to maintain over-balance drilling and avoid formation fracture.

Declaration of conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the first author.

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