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Quantitative Assessment of Rock Mechanical Properties on Formation Pressure in Deepwater Niger Delta

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Abstract- The relationship between deformative rock mechanical properties (Young modulus, shear modus, bulk modulus, and Poisson ratio) and pore pressure in Deepwater Niger Delta with the aim of improving pore pressure predictions was explored. The nature of trends existing between these properties and pore pressure was observed, and a sensitivity analysis to measure the strength of the relationship existing between these properties and pore pressure was performed. Furthermore, an XGBoost model was developed to predict pore pressure using the rock mechanical properties. This was compared with models of Eaton, Bowers, and Millers and showed superior performance with evaluation metrics with a percentage absolute average deviation of 5.43% and a mean absolute error of 253.95. This was followed by Eaton's model with a percentage absolute average deviation of 39.36% and a mean absolute error of 1696.25. Bowers' model had a percentage absolute average deviation of 43.65% and a mean absolute error of 1719.66. Miller's model had a percentage absolute average deviation of 72.40% and a mean absolute error of 2726.68. This study significantly advanced the understanding of how rock mechanical properties relates with pore pressure in Deepwater Niger Delta and developed a more efficient pore pressure prediction model using rock mechanical properties.

Index Terms- Rock mechanical properties, Deepwater, Pore Pressure Prediction, Niger Delta

I. INTRODUCTION

Pore pressure is the pressure of the formation fluids in the rock. Rock mechanical properties are physical properties that describe how rocks respond to mechanical forces. This understanding is crucial in drilling to mitigate wellbore stability issues. These properties determine how rocks deform and respond to stress, which directly affects the stress-strain behavior and pore volume changes. Inappropriate estimation of rock mechanical properties can lead to incorrect pore pressure predictions, increasing the risk of wellbore instability, kicks, or blowouts during drilling. The mechanical properties of rocks play a central role in these phenomena because they govern how rocks respond to stress, deform, compact or dilate, in turn how the fluid pressures within the pores change under varying stress states.

Real time drilling operation faces uncertainties, and the most prominent are problems arising from the wellbore. The mud window is the basis for all drilling programs. Inability to accurately determine the formation pressure of the formations to be drilled can result in stuck pipe and formation fracture, amidst other challenges, leading to non-productive time and increased well construction costs. Pore pressure determination helps in determining a safe mud weight window and the application of Geomechanics further reinforces this with respect to wellbore stability.

Rock mechanical properties can be classified as deformative (or elastic) and strength properties amongst others. The deformative rock mechanical properties describes the reversible (elastic) response to stress or small deformations. They control how much volumetric strain, pore volume reduction or expansion, and effective stress occur under applied loads. They include: Young modulus, Shear modulus, Bulk modulus, and Poisson's ratio [1]. The rock mechanical strength properties describes when rocks fail or begin a permanent deformation. They include uniaxial compressive strength (UCS), tensile strength, shear strength, cohesive strength, friction angle, etc.

The rock mechanical properties investigated in this study are the rock deformation properties which include: Young modulus, bulk modulus, shear modulus, and Poisson's ratio.

Poisson's ratio (v) is the ratio of lateral strain to axial strain when a material is subjected to uniaxial stress. Simply, it quantifies the behavior of a rock when compressed in one direction, expanding in the perpendicular direction.

Young modulus, also known as the modulus of elasticity, is a fundamental mechanical property that describes a rock's stiffness (its ability to resist deformation under stress). It is crucial in understanding how subsurface formations will respond to stress during drilling, production, and reservoir stimulation.

Shear modulus (also known as the modulus of rigidity) is a key elastic property of rocks that describes their ability to resist shearing deformation when subjected to stress. It plays an important role in geomechanics, wellbore stability, fracture design, and seismic analysis.

Bulk modulus is a key elastic property of rocks that measures the resistance to uniform compression. It is crucial in understanding how rocks respond to changes in pressure, especially from fluid extraction, injection, and pore pressure changes.

The impact of carbon dioxide on the mechanical properties of clastic reservoir rocks focusing on key geomechanical parameters such as Young modulus, Poisson's ratio, unconfined compressive strength (UCS), cohesion, friction angle, and tensile strength was done. Rock samples were subjected to carbon dioxide saturated brine injection which was followed by a 14-days static reaction period under in-situ conditions. Before and after treatment analysis showed significant reductions in in UCS (23.9%), cohesion (20.5%), friction angle (8.8%), and Young modulus (21.5%) along with a 7.5% decrease in Poisson ratio and tensile strength reduction of 26%. Uniaxial Pore Volume Compressibility (UPVC) tests showed minor matrix deformation without pore collapse, which was suggested to mean that the rock matrix retains mechanical integrity in the transient pressure variations [2].

The effects of 100% water saturation and 100% crude oil saturation on geo-mechanical properties of unconsolidated reservoir rocks was investigated. Unconfined compressive strength (UCS) test was conducted on nine (9) core samples (three dry samples, three fully saturated with oil, and three fully saturated with water). The geo-mechanical properties of the reservoir core samples were obtained by generating the stress-strain relationship from the conducted UCS test [3].

The failure pattern and mechanical properties of granite rock was investigated. The results of the study showed the importance of considering multiple techniques when investigating the mechanical properties of rock and performing a combination of tests that ultimately provide a complete understanding of the mechanical behavior of rock. The study highlighted the need for further research to deepen the understanding of the relationship between rock failure patterns and mechanical properties and to improve the accuracy and precision of rock property measurements [4].

Numerous studies has been carried out on rock mechanical properties, however, impacts on pore pressure in Deepwater Niger Delta lacks investigation. Illustrating this relationship existing between the rock mechanical properties and pore pressure fills this gap. Furthermore, quantitatively measuring the strength of the correlation between these properties and pore pressure fills this gap.

Pore pressure prediction is most times carried out using indirect pore pressure estimation which relies on models. Rock mechanical properties significantly influence the generation, distribution, and prediction of pore pressures. The variations in deformative rock mechanical properties and their influence in formation pressure needs to be explored, as this deformative rock mechanical properties are elastic.

The impacts of rock mechanical properties on pore pressure in Deepwater Niger Delta remains under investigated. This research aims at investigating the impacts of rock mechanical properties on pore pressure to improve pore pressure predictions. The extent of the impacts of rock mechanical properties needs to be ascertained to fully understand pore pressure behavior. The rock mechanical properties investigated are the deformative properties (Young modulus, bulk modulus, shear modulus, and Poisson's ratio which) which were extracted from well logs using empirical relationships. An artificial intelligence model to predict pore pressure using rock mechanical properties was developed.

In carrying out this study, stress state analysis was not investigated. Also, the results of laboratory experiments on rock samples was not used and effects of temperature were not considered.

II. MATERIALS AND METHOD

This study employed a structured and quantitative data analysis methodology to investigate the relationship between rock mechanical properties and pore pressure. The analysis was focused on understanding the relationship between rock mechanical properties and measured pore pressure data.

The study was in Deepwater Niger Delta region which is located in the Atlantic coast of Southern Nigeria and is the world's second largest delta with that ends at the Imo River entrance. The region is the largest wetland in Africa and among the third largest in the world. The Delta mangrove swamp is the largest mangrove swamp in Africa. The Niger Delta area consists of rivers, creeks, and estuaries. The Niger Delta is classified as a tropical rainforest with ecosystems comprising of diverse species of flora and fauna both aquatic and terrestrial species. The region can be classified into four ecological zones: coastal inland zone, freshwater zone, lowland rainforest zone, and mangrove swamp zone. The Niger Delta consists of the following states in Nigeria: Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, Imo and Rivers [5,6].

A. Data Acquisition

The dataset utilized for this study was derived from well logging measurements and pressure records acquired from multiple drilled wells in the Niger Delta region of Nigeria, a geologically diverse and hydrocarbon-rich region in southern Nigeria, under strict confidentiality. The datasets include sonic and density logs as well as their corresponding true vertical depth (TVD). Measured pore pressure data for same wells was also used.

Rock mechanical properties such as Young modulus, bulk modulus, shear modulus, and Poisson's ratio were derived from combinations of the sonic and density logs using well-established Geo-mechanical equations. These derived parameters were also paired with depth and pore pressure data to provide additional insight into formation behavior.

Before the research was carried out, the collated data was first processed. The data processing involved data cleaning such as removing outliers and null values. The dataset was then transformed. Units of measurements were checked and converted to ensure that all parameters were in the same units of measurements.

The sampling technique adopted for this study is a combination of purposive sampling and stratified random sampling. Purposive Sampling was used initially to select wells that had complete and high-quality data. Wells with known anomalies, incomplete logs, or missing pressure data were excluded to maintain data integrity. Stratified Random Sampling was then used within the selected wells to ensure that the data represents all depth intervals and lithological variations. Each stratification layer represented a zone or formation of interest (e.g., shale, sandstone, or reservoir intervals), and within each stratum, random sampling was performed to select data points.

B. Rock mechanical properties

Geo-mechanical equations utilized in this study for the estimation of the rock deformation properties (Young's modulus, bulk modulus, shear modulus, and Poisson's ratio) involve the combinations of the sonic and density logs as presented.

Poisson's ratio (v) is the ratio of shearing stress to longitudinal strain and is expressed as:

$$\gamma = \frac{(0.5\Delta T_s^2 - \Delta T_p^2)}{(\Delta T_s^2 - \Delta T_p^2)} \qquad (1)$$

Where γ is the Poisson ratio, ΔT_p is the compressional transit time, ΔT_s is the shear wave transit time.

Young's modulus is the ratio of Normal stress to longitudinal strain and is expressed as below:

$$E = \frac{\rho_b(3\Delta T_s^2 - 4\Delta T_p^2)}{[\Delta T_s^2(\Delta T_s^2 - \Delta T_p^2)]} \qquad (2)$$

Where E is Young Modulus, ρ_b is the bulk density, ΔT_p is the compressional transit time, ΔT_s is the shear wave transit time.

Shear modulus is the ratio of shear stress to shear strain, expressed below:

$$G = \frac{E}{2(1+\gamma)} \qquad (3)$$

Where G is shear modulus, γ is the Poisson ratio, and E is Young Modulus.

Bulk modulus is the ratio of normal stress to volumetric strain expressed below:

$$K_b = \frac{E}{3(1-2\gamma)} \qquad (4)$$

Where K_b is bulk modulus, γ is the Poisson ratio, and E is Young Modulus.

Table 1 provides a summary of log types from which each rock mechanical property can be obtained.

Table 1: Derived mechanical properties and the log types

Property Derived	Log	Unit
Poisson's ratio	Sonic	-
Young modulus	Density and Sonic	GPa
Shear modulus	Density and Sonic	GPa
Bulk modulus	Density and Sonic	GPa

C. Correlation Analysis

The analysis was focused on analyzing the nature of the relationship existing. Statistical analysis was first carried out on the dataset to get a description of it. Trend analysis of the rock mechanical properties and pore pressure was carried out. This was to illustrate the nature of the trend existing between the rock mechanical properties and formation pore pressure. Pearson correlation as presented below was utilized to determine how the features relate amongst themselves and with pore pressure. The analysis was carried out to determine the strength of correlation existing amongst them. The Pearson correlation coefficient as presented in equation 5, shows the strength of the correlation between two variables. The range is between +1 (perfect positive correlation) to -1 (perfect negative correlation), with zero (0) indicating no correlation. The coefficient is unaffected by the units of measurement, thus ensuring comparability across different scales. The correlation between two variables remains consistent regardless of the variable order (X with Y, or Y with X) [7].

$$p(x,y) = \frac{\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{j=1}^{n} x_j\right)\left(y_i - \frac{1}{n}\sum_{j=1}^{n} y_j\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{j=1}^{n} x_j\right)^2}\ \sqrt{\sum_{i=1}^{n}\left(y_i - \frac{1}{n}\sum_{j=1}^{n} y_j\right)^2}}$$

(5)

D. Model Development

Extreme Gradient Boost was used to develop the model for the prediction of pore pressure. The XGBoost model (Extreme Gradient Boosting) used in this study was designed as a powerful, tree-based regression model to predict pore pressure from well log data. The dataset was first preprocessed using "StandardScaler" to normalize the independent variables (Young's modulus, bulk modulus, shear modulus, and Poisson's ratio) ensuring that feature magnitudes did not disproportionately affect model learning. The data was split into training (80%) and testing (20%) sets for model validation. A hyperparameter tuning process using "GridSearchCV" was employed to optimize the model. The parameters explored included "max_depth", "learning_rate", "n_estimators", and "subsample". These control tree complexity, learning dynamics, ensemble size, and sampling strategies, respectively. Cross-validation (cv=3) was used to reduce overfitting and to evaluate the generalization of each hyperparameter set based on negative MAE (mean absolute error).

XGBoost is a tree-based ensemble model, optimized using "GridSearchCV". XGBoost, being a boosting algorithm, builds decision trees sequentially. Each new tree attempts to correct the errors made by the ensemble of previous trees by minimizing a regularized objective function. This makes it highly efficient and suitable for capturing non-linear relationships between well logs and pressure.

A flow chart for the development of the model and comparative analysis is as shown in the figure below.

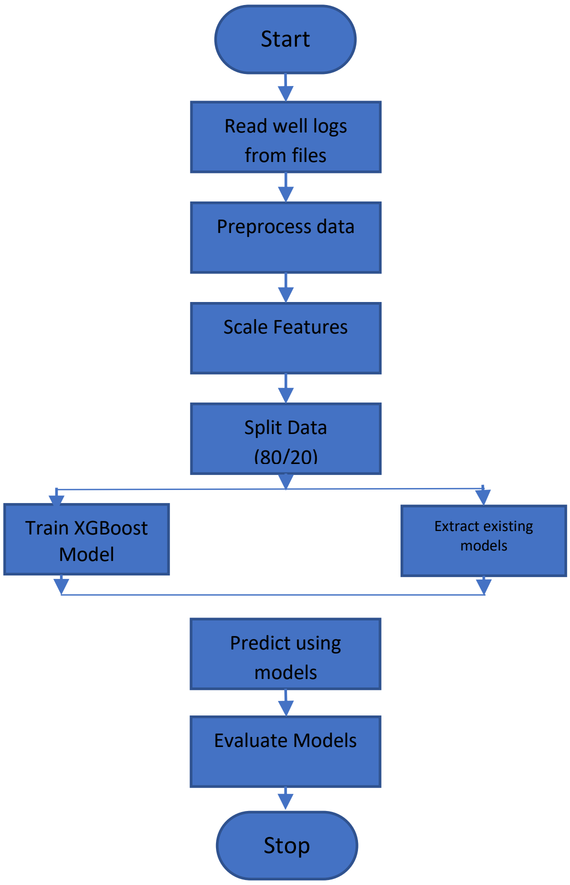

Figure 1: Flowchart for model development and evaluation

E. Comparative Analysis

The developed model was compared against models of Eaton, Bowers, and Millers. The analysis was focused on performing pore pressure predictions with models of Eaton, Bowers, and Millers as provided in Equations 6 to 10 and making quantitative comparisons between models' predictions and measured pore pressure data.

Eaton's sonic model [8] is as presented in equation 6:

$$P_p = \sigma_v - (\sigma_v - P_n)\left(\frac{\Delta t_n}{\Delta t}\right)^n \qquad (6)$$

Where, σ_v is the vertical stress, P_n is normal pore pressure, Δt is the sonic transit time in shales obtained from well log, Δt_n is the sonic transit time in shales, n= 3.

Bowers proposed the model for sonic velocity of shale and effective stress is as presented in equation 9 but obtained from equations 7 and 8 [9]:

$$V_p = V_{ml} + A\sigma_e^B \qquad (7)$$

Where V_p is the compressional velocity at a given depth, V_{ml} is the compressional velocity in the mudline (that is the seafloor or the ground surface, normally $V_{ml} \approx 5000, or\ 1520\ m/s$), $\sigma_e$is the vertical effective stress, A and B are the parameters obtained from calibrating regional offset velocity versus effective stress data.

Replacing,

$$\sigma_e = \sigma_v - P \qquad (8)$$

Where P is the pore pressure

$$P = \sigma_v - \left(\frac{V_p - V_{ml}}{A}\right)^{\frac{1}{B}} \qquad (9)$$

Where A= 10-20 and B=0.7 – 0.75, where P, σ_v, are in psi, and V_p, V_{ml} are in ft/s

Miller's sonic method was presented to describe a relationship between velocity and effective stress that can be used to relate sonic/seismic transit time to formation pore pressure, as presented in equation 10:

$$P = \sigma_v - \frac{1}{\lambda}\ln\left(\frac{V_m - V_{ml}}{V_m - V_p}\right) \qquad (10)$$

Where V_m is the sonic interval velocity in the matrix of the shale (asymptotic travel time at infinite effective stress, V_p is the compressional velocity at a given depth, λ is the empirical parameter defining the rate of increase in velocity with effective stress (normally 0.00025).

Performance evaluation of the developed model and the existing models analyzed in this study, was done using mean absolute error and percentage average absolute deviation to quantify the errors. Mean absolute error (MAE) as presented in equation 11, was calculated for the models' predictions. To measure quantitatively the level of deviation the models' predictions have from the measured pressure data, percentage average absolute deviation (PAAD) as presented in equation 12, was utilized.

Mean Absolute Error (MAE):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|x_{actual} - x_{predicted}\right| \qquad (11)$$

Percentage Average Absolute Deviation (%AAD):

$$\%AAD = \frac{1}{n}\sum\left|\frac{x_{actual} - x_{model}}{x_{actual}}\right| \qquad (12)$$

III. RESULTS

This section presents the results obtained from the research. Table 2 presents a statistical summary of the derived rock mechanical properties, which were computed from the available well log data. Figure 2 to 5 displays the trends of the rock mechanical properties with pressure, namely bulk modulus, shear modulus, Young modulus, and Poisson ratio respectively. Figure 6 displays the sensitivity matrix of the rock mechanical properties and pore pressure. Figure 7 and 8 presents 2 out of the developed 1,000 decision trees. Figure 9 presents comparisons of pore pressure predictions made using rock mechanical properties through XGboost and predictions made with existing models using well log properties. Table 3 presents the models performance analysis of the predictions.

Table 2. Statistical description of derived rock mechanical properties

Parameters	Min	Max	Range	Mean	Kurtosis	Skewness	Coefficient of Variance
Young modulus	3.9e-05	0.000159	0.00012	8.674e-05	2.34297	0.4209	33.8340
Shear modulus	1.37e-05	6.16e-05	4.79e-05	3.168e-05	2.45306	0.4873	35.4487
Bulk modulus	5.44e-05	0.0001604	0.000106	0.000114 69	2.55833	-0.188	20.6350
Pressure	3221.35	7230.03	4008.68	4658.649 50	2.97310	0.5515	19.0793

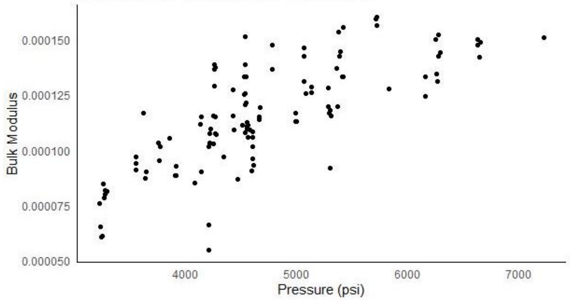

Figure 2. Bulk modulus and pressure relationship

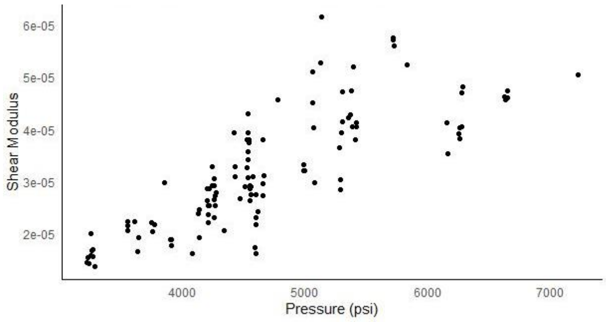

Figure 3. Shear modulus and pressure relationship

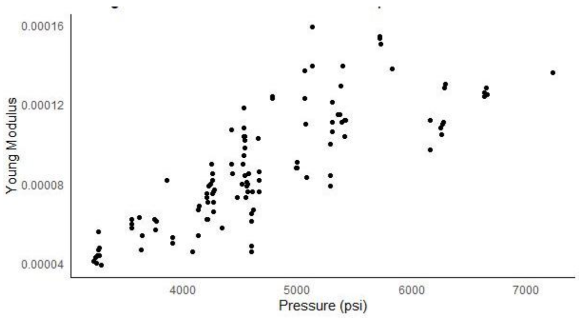

Figure 4. Young modulus and pressure relationship

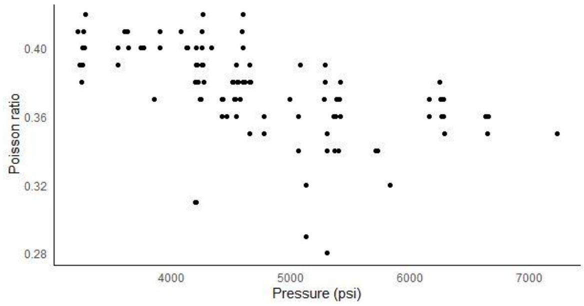

Figure 5. Poisson ration and pressure relationship

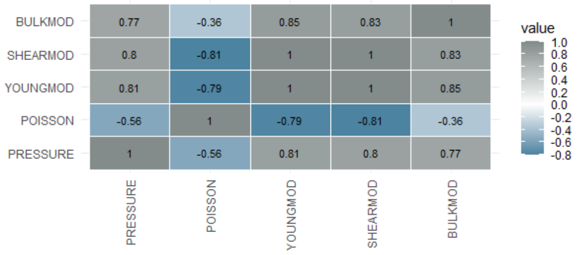

Figure 6. Sensitivity matrix of derived rock mechanical properties and pressure

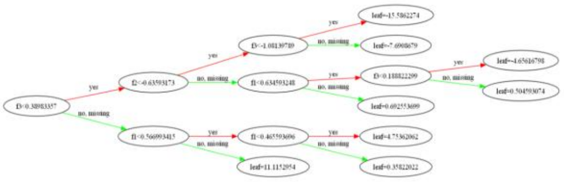

Figure 7: Decision tree 0 of 999

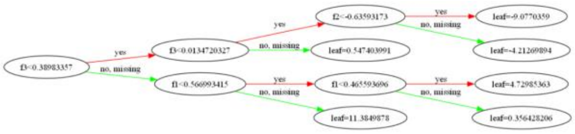

Figure 8: Decision Tree 1 of 999

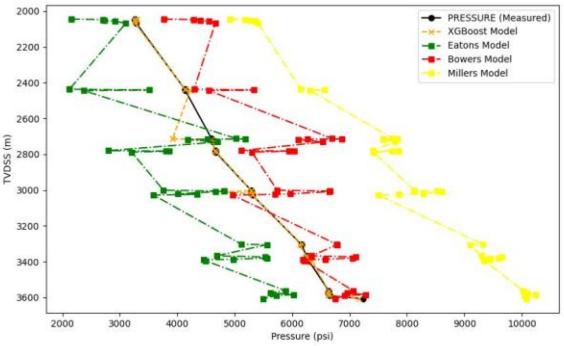

Figure 9: Comparison of pore pressure predictions

Table 3: Models performance analysis for different Deepwater wells

Models	MAE	PAAD (%)
XGBoost Model	253.95	5.43
Eaton Model	1696.25	39.36
Bowers Model	1719.66	43.65
Millers Model	2726.68	72.4

The bulk modulus quantifies a material's resistance to uniform compression. The upward trend in the relationship of bulk modulus and pressure in Figure 2 is an indication that the rock or material becomes increasingly resistant to compression as pressure increases. This phenomenon is known as non-linear elastic stiffening. Pore spaces close when confining pressure increases, this leads to stiffer rock. This implies that the rock becomes less compressible with increasing pressure. This causes an increase in bulk modulus. The bulk modulus of a porous rock increases with confining pressure. This increase is rapid initially due to the closure of microcracks and compliant pores. But at higher pressures, the increase slows as the rock approaches the modulus of the solid matrix [10].

Shear modulus quantifies a materials resistance to shear deformation. In the relationship between shear modulus and pore pressure as presented in Figure 3, the upward trend reveals that rock stiffness increases with pressure. This is because as pressure increases, the microcracks close which enhances grain-to-grain contact and thus increases the rocks rigidity. Conversely, this implies that at low pressures, rocks deform more easily due to open micro cracks. At higher pressures, shear resistance increases, hence higher shear modulus. The observed upward scatter reflects the heterogeneity of the subsurface. Shear modulus is entirely dependent on the rock frame stiffness and is not affected by pore fluid. It increases with confining pressure due to closure of cracks and strengthening of grain contacts [10].

Young modulus is a measure of a material's resistance to axial (elastic) deformations. From the trend observed in Figure 4 between Young modulus and pore pressure, as pressure increases Young modulus increases. This is because as pressure increases cracks close and grain contacts tighten, this makes the rocks less deformable. Thus, higher pressures make rocks stiffer and more elastic, thus increasing Young modulus.

Young modulus increases with pressure due to the compaction and stiffening of the rock frame. The relationship is non-linear, especially in cracked or porous rocks where the closure of features dominates the mechanical response [10]. Rocks exhibit a substantial increase in elastic stiffness as confining pressures increase. This results in an increase in Young modulus especially in formations that has significant microcrack features [11].

The trend of Poisson ratio and pressure relationship as presented in Figure 5 shows an inverse relationship existing between Poisson ratio and formation pore pressure. The decreasing trend suggests that the rock becomes more brittle or less capable of deforming laterally under vertical stress as pressure increases. This also implies that as pressure increases shear modulus increases faster than bulk modulus, shear velocity also increases faster than compressional velocity which leads to lower Poisson's ratio.

Poisson's ratio tends to decrease with increasing pressure due to closure of compliant pores and cracks. This leads to a faster increase in shear velocity relative to compressional velocity [10].

The sensitivity matrix of derived rock mechanical properties and pressure are presented in Figure 6. This matrix is made from the results of Pearson's correlation. From the figure, it can be observed that the correlation strength with pressure, of Bulk modulus, shear modulus, and Young modulus is high with values of: 0.77, 0.8, and 0.81 respectively. This shows that they have high correlation strength with formation pore pressure. However, Poisson ratio has a value of -0.56, showing a moderate correlation strength with formation pore pressure.

The Pearson correlation analysis between bulk modulus and other rock mechanical properties reveals critical insights into the mechanical behavior of subsurface formations and their influence on pore pressure. The strong positive correlation between bulk modulus and shear modulus (value of 0.83), and Young's modulus (value of 0.85) is consistent with the mechanical interdependence of these elastic properties. Bulk modulus, which measures a material's resistance to uniform compression, is inherently related to both Young modulus (which quantifies stiffness) and shear modulus (which measures resistance to shape deformation), as they are all derived from the same elastic theory framework [11, 10]. This correlation signifies that stiffer and more mechanically competent rocks also tend to be less compressible, a characteristic typical of compacted and cemented formations.

Conversely, the low negative correlation between bulk modulus and Poisson's ratio (value of –0.36) reflects the inverse relationship between compressibility and the ability of a material to deform laterally under stress. Rocks with higher Poisson's ratio tend to be more ductile and compressible, often indicative of shale-rich formations with higher clay content or over-pressured zones [12].

Moreover, the strong positive correlation between bulk modulus and pore pressure (value of 0.77) highlights the link between rock mechanical rigidity and abnormal pressure zones. As pore pressure increases, especially in deep formations such as those in the Niger Delta, compaction may be resisted by the elevated pore fluid pressure, resulting in stiffer, high-modulus formations [13, 14]. This is particularly relevant in geopressured environments where mechanical properties evolve due to ongoing sediment loading and pressure buildup. High bulk modulus values in such zones suggest a decreased ability of the rock to compress further, which may help in constraining pore pressure models and improving wellbore stability predictions.

The Pearson correlation analysis between shear modulus and other rock mechanical properties reveals significant geo-mechanical relationships pertinent to pore pressure prediction and subsurface formation behavior. A perfect positive correlation between shear modulus and Young modulus (value of 1.00) indicates a direct and consistent linear relationship, affirming their theoretical interdependence in elastic theory. Both moduli are functions of the same parameters (bulk modulus and Poisson's ratio) and are used to describe the stiffness and rigidity of geological formations [11, 10]. This perfect correlation is often observed in homogeneous, isotropic elastic materials and suggests that as one property increases, the other does so proportionally, which is typical in consolidated and competent formations.

On the other hand, the strong negative correlation between shear modulus and Poisson's ratio (value of –0.81) aligns with established rock mechanics theory. A high Poisson's ratio often indicates ductile, less rigid formations such as shales, which tend to deform more laterally under axial stress, whereas high shear modulus values correspond to more rigid, elastic rocks like sandstones or carbonates [12]. This inverse relationship is critical in geo-mechanical modeling, as it helps distinguish between rock types and mechanical behaviors in the subsurface.

Furthermore, the strong positive correlation between shear modulus and pore pressure (value of 0.80) is indicative of the role that elevated pore pressure plays in stiffening rock formations, especially in over-pressured regimes such as those frequently encountered in the Niger Delta. Increased pore pressure can contribute to porosity reduction and lithification over time, thereby enhancing the shear rigidity of the formation [13, 14]. This relationship suggests that areas with high pore pressure may exhibit increased shear strength, which is a crucial consideration in wellbore stability analysis and hydraulic fracturing design.

The strong negative correlation between Young modulus and Poisson's ratio (value of –0.79) suggests that formations with higher stiffness (indicated by high Young's modulus) tend to deform less laterally under axial stress, hence exhibiting lower Poisson's ratios. This inverse relationship is consistent with classical elasticity theory, where an increase in rock stiffness usually correlates with a decrease in ductility; the properties that are inversely captured by Young's modulus and Poisson's ratio, respectively [11, 10]. In practical geological terms, formations such as tightly cemented sandstones or carbonates often exhibit this behavior, whereas more ductile formations like shale tend to display the opposite.

Additionally, the strong positive correlation between Young modulus and pore pressure (value of 0.81) indicates that as pore pressure increases, the elastic stiffness of the rock also tends to increase. This relationship may be attributed to the effect of compaction and diagenesis in over-pressured zones, where fluid support within the pore spaces contributes to mechanical strength and apparent rock rigidity [13]. In sedimentary basins such as the Niger Delta, this can signify those over-pressured formations, especially those at greater depths, may possess higher stiffness due to reduced porosity and increased cementation, which enhances the Young modulus.

The Pearson correlation analysis between Poisson's ratio and pore pressure reveals a moderate negative correlation (value of –0.56), indicating that as pore pressure increases, Poisson's ratio tends to decrease. This inverse relationship implies that formations under higher pore pressure conditions often exhibit less lateral deformation relative to their axial deformation, which is counterintuitive but geomechanically significant. Typically, Poisson's ratio is a measure of a material's ductility (higher values suggest a more ductile, deformable rock, while lower values indicate brittleness and higher stiffness) [11].

In many over-pressured formations, compaction and diagenetic processes reduce porosity and increase rock stiffness, leading to lower Poisson's ratios. These formations are often more brittle and less prone to lateral strain, explaining the observed decrease in Poisson's ratio with increasing pressure. This behavior is particularly relevant in petroleum geomechanics, where accurate characterization of elastic properties under varying pressure conditions is essential for wellbore stability, fracture prediction, and sand production risk assessments. In shale formations, increased pore pressure may reflect over-compaction or hydrocarbon generation, both of which affect the mineralogical composition and mechanical behavior of the rock [13, 10]. Moreover, lower Poisson's ratios in high-pressure zones may indicate increased potential for brittle failure, making this correlation valuable in hydraulic fracturing design and seal integrity evaluation.

A total of 1000 trees where developed using Extreme Gradient Boost as shown in Figure 7 and 8.. These trees are connected and constitute the decision trees developed for the prediction of pore pressure. In comparing the Artificial Intelligence pore pressure prediction model developed using Extreme Gradient Boost with existing models of Eaton, Bowers, and Millers Figure 9 gives an illustration of the predictions made. From the figure, Millers model over-predicted pore pressure, Eaton's prediction was close to the measured pore pressures, followed by Bowers. In comparison with the trained XGBoost model, the XGBoost model developed, performed and was superior in prediction appearing almost in line with the measured values.

Quantitatively, from the errors measured from the predictions presented in Table 3, the XGBoost model had better performance with a percentage absolute average deviation of 5.43% and a mean absolute error of 253.95. This performance was followed by Eaton's model with a percentage absolute average deviation of 39.36% and a mean absolute error of 1696.25. Bowers' model had a percentage absolute average deviation of 43.65% and a mean absolute error of 1719.66. Miller's model had a percentage absolute average deviation of 72.40% and a mean absolute error of 2726.68.

From the results, the model developed in this study performed better than the existing models.

IV. CONCLUSION

This study aimed at investigating the impacts of rock mechanical properties on pore pressure. By analyzing rock mechanical properties and pore pressure, the study established the relationship existing and the strengths of the relationship. Additionally, an Artificial Intelligence pore pressure prediction model was developed. This developed model performed better in comparison with existing models. The XGBoost model had a percentage absolute average deviation of 5.43% and a mean absolute error of 253.95, this performance result was followed by Eaton's model with a percentage absolute average deviation of 39.36% and a mean absolute error of 1696.25.

Further works should be done on exploring rock mechanical properties and seal integrity relationship.

This study has significantly advanced the understanding of how the rock mechanical properties relates with pore pressure, by revealing in a quantified manner, the strengths of the relationships. This work lays a strong foundation for continued progress in pore pressure and wellbore stability.

This study has contributed to the advancement of literature in Drilling Engineering.

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