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# An Analytical Model of Unconfined Compressive Strength and Compressional Wave Velocity, in the Northern Depobelt of Onshore Niger Delta, Nigeria.

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***Abstract:*** *The maximum axial compressive stress capacity, of a material or structure to withstand load before failing, is regarded as the unconfined compressive strength (UCS). This is one of the most important parameters necessary for the estimation of mechanical properties of rock materials, in Rock Engineering Projects. Adequate understanding of rock strength will greatly aid the control and management of hydrocarbon drilling challenges, which includes, pipe sticking, tight hole, collapse-pack-off and sand control. To all intent and purpose, the determination of unconfined compressive strength (UCS) requires a rigorous and high-cost intensive laboratory work. This study presents the development of a robust analytical model of unconfined compressive stress, derived from slowness. Quality checked Sonic logs, from four (4) wells in the Niger Delta were employed in the development of the model, UCS = 924.46*exp(-0.035DT$_p$). The coefficient of determination ($R^2$) of the obtained model was 0.98. The new model is highly diagnostic, non-destructive and inexpensive in the determination of unconfined compressive strength (UCS). The developed model in this study is found to be a robust tool for the determination of rock strength, drilling operations, geopressure analysis, compaction trend determination and perforation operations in the oil and gas exploration.*

***Keywords:*** *geomechanical, UCS, Niger Delta, siliciclastic, geopressure*

## I. Introduction

The maximum axial compressive stress capacity, of a material or structure to withstand load before failing, is regarded as the unconfined compressive strength (UCS). This is one of the most important parameters necessary for the estimation of mechanical properties of rock materials, in Rock Engineering Projects. Adequate understanding of rock strength will greatly aid the control and management of hydrocarbon drilling challenges, which includes, pipe sticking, tight hole, collapse-pack-off and sand control.

Unconfined Compressive Strength (UCS) test is widely used for estimating the mechanical properties of rock materials. This involves the use of mathematical and empirical relationships. UCS is directly measured according to the American Society for Testing Materials (ASTM), the International Society for Rock Mechanics[1] and other common standards [2]. Rock mechanical laboratory testing on core samples are the most accurate methods for the estimation of rock strength, but they never can lead to a continuous profile of rock strength along wellbore. Coring is very expensive and results are very sensitive to stress unloading. However, the indirect method which were adopted in this study are relatively simple and generally do not require any sample preparation as compared to the direct techniques. In the direct methods, UCS values are predicted with a simple mathematical model in a simpler, faster and more economical way. [3] has observed that UCS derived from

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empirical relationships gives more accurate results when compared to that from static measurements because of poor sample preparation and handling.

There are several correlations established in estimating UCS from $V_p$. [4] and [5] developed an empirical correlation between UCS and slowness parameter ($DT_p$) in sandstones and shale, respectively. [6] proposed a correlation in estimation of UCS for granite under dry condition.[7] developed an empirical correlation for sandstones using $V_p$ and density. [8] derived UCS Equations for Benin and Upper Agbada formations (shales) from core samples. [9] established a new empirical relation after plotting the cores obtained from 26 samples of Malaysian dry schist. It is revealed that the laboratory results are not in good agreement with the established empirical correlations, as it predicts too low the value of UCS, hence the new Equation. [10] have studied the contribution of rock anisotropy to seismic velocities on schist. This study revealed that primary wave velocity is higher when the seismic wave travels at ninth (90°) degrees perpendicular to the foliation of schist, compared to when the seismic waves travel at zero (0°) and forty-five (45°) degrees to the foliation of schist. The results clearly show that effects of anisotropy must be taken into consideration in interpretation of data. A study by [11] shows that saturated rock has higher $V_p$ when compared to unsaturated rock. Thus, it is important that these rock properties are taken into account whenever estimation of UCS is made by utilizing $V_p$.
Table 1 summarizes the empirical correlation established by various authors in estimating UCS.

**Table 1: Empirical relationships between UCS and P-wave velocity ($V_p$)**

| Reference | UCS (MPa) | Lithology | Sample Condition |
|---|---|---|---|
| McNally (1987) | $1200 \bullet exp^{(-0.036DTp)}$ | Sandstone | Saturated |
| Moos *et.al,* (1999) | $(1.745 \times 10^{-9})\ \rho V_p^2$ | Sandstones | Saturated |
| Horsrud (2001) | $0.77 \bullet [304.8 / DTp]^{2.93}$ | Shales | Saturated |
| Goh *et.al*, (2014) | $(2.55 \times 10\text{-}5) \bullet V_p^{1.7658}$ | Granite | Dry |

## II. Geology of The Study Area

The study area, '*DL*' Field, is located within the central parts of the Northern Depobelt in the Niger Delta oil and gas province. The area lies between Latitudes 5.5° to 5.7° N and Longitudes 6.3° to 6.7° E. (Fig 1). The Niger Delta is situated in the Gulf of Guinea (Fig 1) and extends throughout the Niger Delta Province as defined by [12]. From the Eocene to the present, the delta has prograded south-westward, forming Depobelts that represent the most active portion of the delta at each stage of its development [13]. These Depobelts form one of the largest regressive deltas in the world with an area of approximately 300,000 km$^2$ [14], it has a sediment volume of 500,000 km$^2$ [15], and a sediment thickness of over 10 km in the basin depocenter [16].

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and south-western Cameroon. The northern boundary is the Benin flank--an east-northeast trending hinge line south of the West Africa basement massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east- South-East by the Calabar flank - a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west, and the two-kilometre sediment thickness contour or the 4000m bathymetric contour in areas where sediment thickness is greater than two kilometres to the south and southwest. The province covers 300,000km$^2$ and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System. The Niger Delta Province contains only one identified petroleum system [14,17]. This system is referred to here as the Tertiary Niger Delta (Akata-Agbada) Petroleum System.

[18 and 19] in their research stated that the Tertiary Niger Delta is divided into three main formations, which represent the prograding depositional facies of sand and shale. The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. The second is the Agbada Formation which is the major petroleum-bearing unit. Its formation consists of paralic siliciclastics sediments with over 3700 m thickness and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environment. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick.

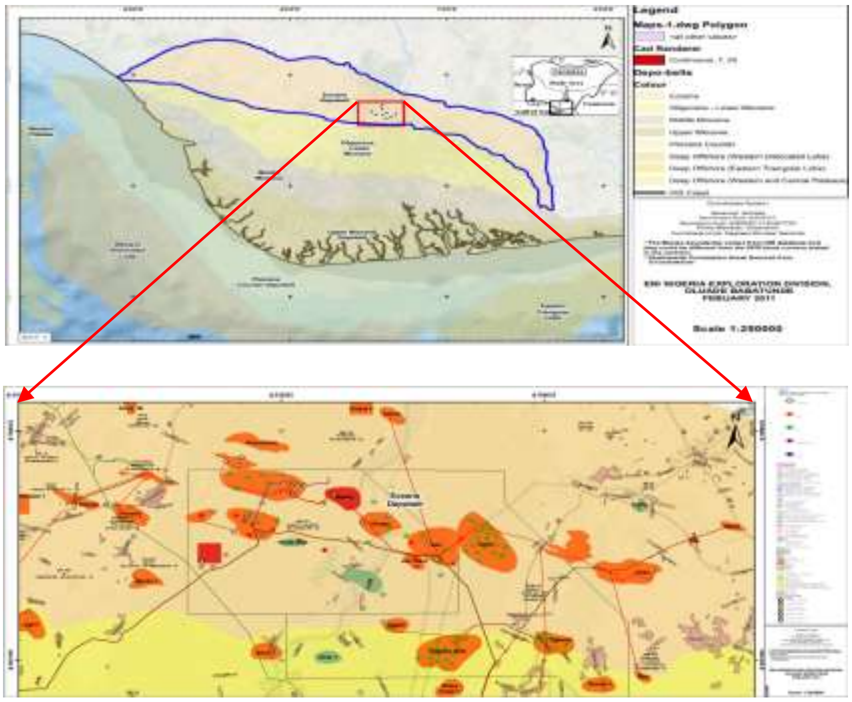

**Fig. 1: Map of Niger Delta showing Study Area (GIS ENI Nigeria, 2011)**

## III. Materials and Method

In executing the study, four (4) composite well logs with tracks consisting of, gamma ray, resistivity, neutron, density and sonic, were employed in the estimation of UCS, with the newly developed empirical Equation for the Niger Delta. The software used was the Schlumberger Techlog64, 2015.3 version. The well logs were carefully conditioned or edited prior to their use in a modelling workflow on Techlog Workstation. The well log conditioning process includes, De-spiking and filtering to remove or correct for anomalous data points, normalization of the logs to determine the appropriate ranges and cut-offs for porosity, clay content, water resistivity and Saturation.

**3.1 Shear Velocity Modeling Calibration**

In this study, P-wave and S-wave velocities were determined using the Equation given by [20]. The P-wave velocity was obtained from Equation 1 which is the relationship between wave velocity and sonic log readings, where Vp is the primary wave velocity measured in m/s and sonic transit time ($DT_p$) measured in µsec/ft.

For the purpose of modelling and calibrating shear velocity for accurate determination of the inelastic property, UCS, from wireline well logs, the values in Table 2 were used extensively for accurate calibration, two shear wave Equations were considered in accordance to [20]. [20], indicates that one of the share wave Equations was used in sandstone domain while the other was used in the shale domain for the correlation, as shown in Fig. 2 and Equations 2 and 3 respectively.

| Lithology | $a_{i2(quadratic)}$ | $a_{i1(linear)}$ | $a_{i0(constant)}$ |
|---|---|---|---|
| Sandstone | 0 | 0.80416 | -0.85588 |
| Shale | 0 | 0.76969 | -0.86735 |
| Limestone | -0.05508 | 1.01677 | -1.03049 |
| Dolomite | 0 | 0.58321 | -0.07775 |

**Table 2: Representative Regression Coefficients for Shear Wave Velocity versus Compressional Wave Velocity in Pure Porous Lithologies** Castagna *et al* (1992) **[20]**

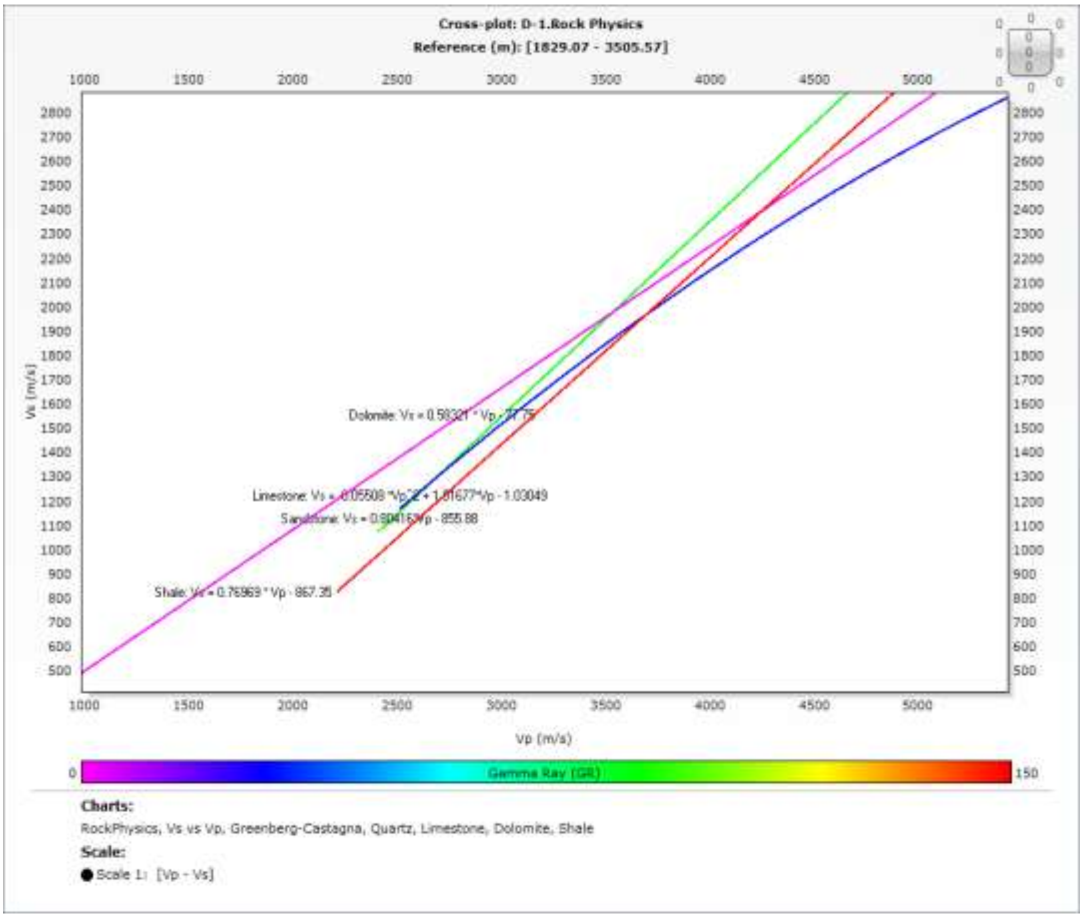


**Fig. 2: Shear Velocity Modelling Calibration Standard Cross plot [18]**

$$V_p = 1000000*(0.305/DT) \text{ (m/s)} \quad (1)$$

$$V_s = 0.80416V_p - 0.85588 \text{ (km/s) sand} \quad (2)$$

$$V_s = 0.76969V_p - 0.867355 \text{ (km/s) shale} \quad (3)$$

Where DT is the interval transit time recorded by sonic log in µsec/ft and converted into compressional velocity in meters per second (m/s) as indicated in Equation 1.
A model was developed with the IF and ELSE commands in Microsoft Excel as Equation 4 to delineate sand and shale lithologies using the Gamma ray log as lithology log and scaled from 0 to 150 GAPI. Cutoff of 80 GAPI was applied to Gamma ray dataset as a transition zone between the two lithologies. 0 to 79 GAPI was modeled as sand zone, while 80 to 150 GAPI was modeled as shale. The essence of the delineation was to achieve the shear velocity modelling calibration in both sand and shale lithologies being the dominate lithologies in Niger Delta for accurate determination of the rocks geomechanical properties.

$$IF(GR<80,(0.80416*V_p)-0.85588,(0.76969*V_p)-0.86735) \quad (4)$$

Equation 4 therefore, was integrated into the model for the determination of the elastic and inelastic properties presented in this study. Shear velocity modelling calibration was significant in study as it ensures that subsurface models accurately reflect the geological reality. This led to improved subsurface imaging, enhanced reservoir characterization, reduced exploration and drilling risks, and more efficient hydrocarbon production, contributing to the overall success of exploration and production activities in the oil and gas industries in the study area.

**3.2 Determination of Inelastic Property**

Determination of inelastic rock properties is a critical aspect of geotechnical engineering and rock mechanics, especially when analyzing how rocks respond to various loads and stresses. Inelastic behaviour refers to the irreversible deformation or failure of rock materials beyond their elastic limit. It encompasses plasticity, creep, and failure due to fracture or faulting. Some common methods and considerations for determining inelastic rock properties, includes unconfined compressive strength (UCS), triaxial compression test, uniaxial compression test, creep testing and laboratory rock fracture test are few examples for determining inelastic rock properties.

**3.2.1 Unconfined Compressive Strength (UCS)**

Rock strength correlation has been performed in other regions of the world but in the Niger Delta region, no specific empirical relationship and correlation has been published across the Depo Belts in the region. Although, [8] derived UCS equations for Benin and Upper Agbada formations (shales), eq. 3.28. This equation has limitation because it does account for the entire drilled well column. Only specific reservoir of interest was measured thereby limiting its scope.

$$0.24\left[\frac{304.8}{DT}\right]^{2.664} \quad (5)$$

This empirical equation, presents meaningful comparison between the different empirical relations and algorithms in the Niger Delta. The petrophysical logs allow for computation of continuous mechanical properties with depth. These log-derived rock mechanical properties in the Niger Delta, were correlated with derived rock mechanical properties from other authors across the regions for validation.

## IV. Results and Discussions

The results of UCS and $V_p$ computed from sonic data for the (four) wells 1,2,3 & 4 within Field 'DL' are presented in Tables 3, 4, 5 and 6 respectively with the newly developed empirical equation,

$$UCS = 924.46*\exp(-0.035DT_p) \quad (6)$$

The modelled Equation has a coefficient of determination ($R^2$) of 0.98 as shown in Fig 3. The new developed empirical equation, provides better way to carry out UCS analysis in the Niger Delta as it considers the effects of anisotropy and water condition of rock. The new developed equation is in agreement with other established empirical equation such as [4], [9] and [2] as presented in Figs 3, 4, 5 and 6 respectively. Statistical analysis presented in Table 3 shows significant variations from each other because P≤0.05. However, values with same superscripts are not significantly different from each other. Therefore, [9] equation and new developed empirical equation are not significantly different.

Again, the shear velocity modelling calibration for lithologic delineation are presented in Figs 7, 8, ,9 and 10 respectively. The results show perfect match with the results obtained by [20] cross plot for sand and shale delineation, Greenberg-Castagna shear velocity calibration and Greenberg-Castagna shale-sand model calibration respectively. Based on these calibration results of the shear velocity, the geomechanical properties of the rocks were computed. The calculated geomechanical properties are as follows: Compressional Velocity ($V_p$), Shear Velocity ($V_s$), $V_p/V_s$ and the UCS as presented in Tables 4, 5, 6 and 7 respectively.

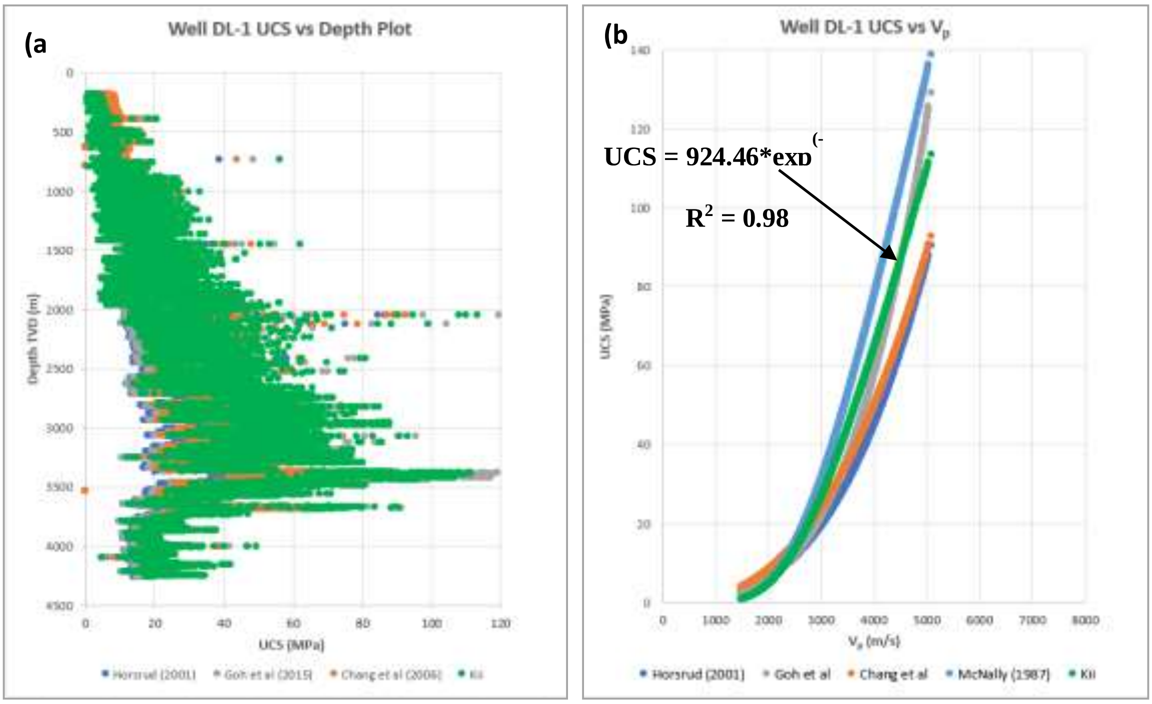


**Fig. 3: comparison of various models with the developed model for Well DL-1 (a) UCS vs depth plot and Shale Delineation, (b) UCS vs $V_p$ plot**

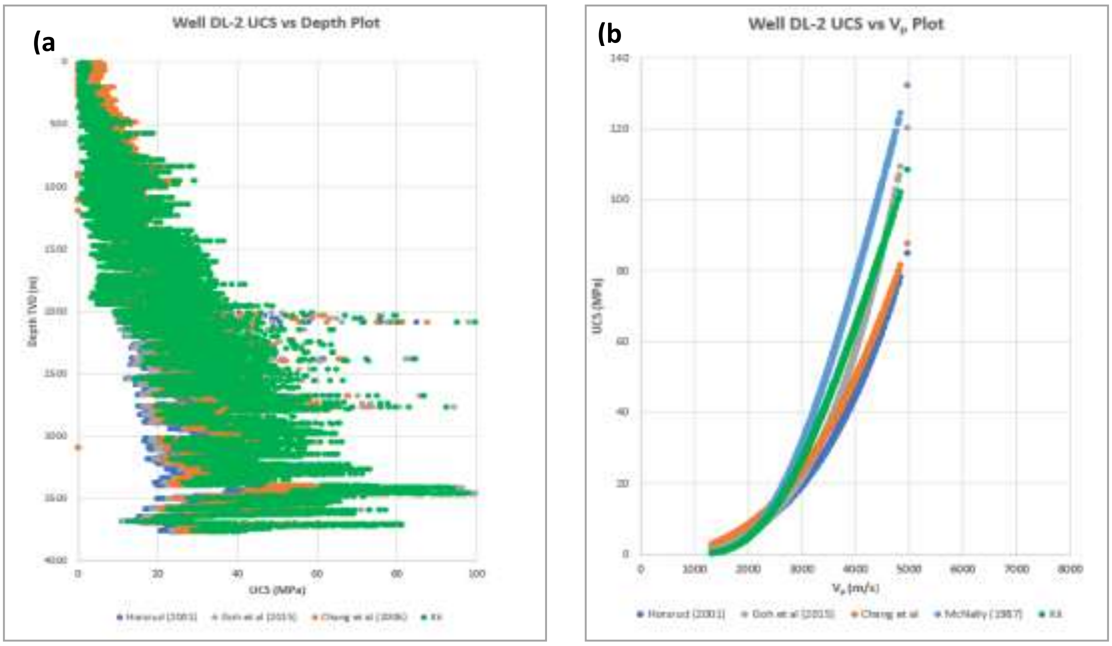


**Fig. 4: comparison of various models with the developed model for Well DL-2 (a) UC vs depth plot and Shale Delineation, (b) UCS vs $V_p$ plot**

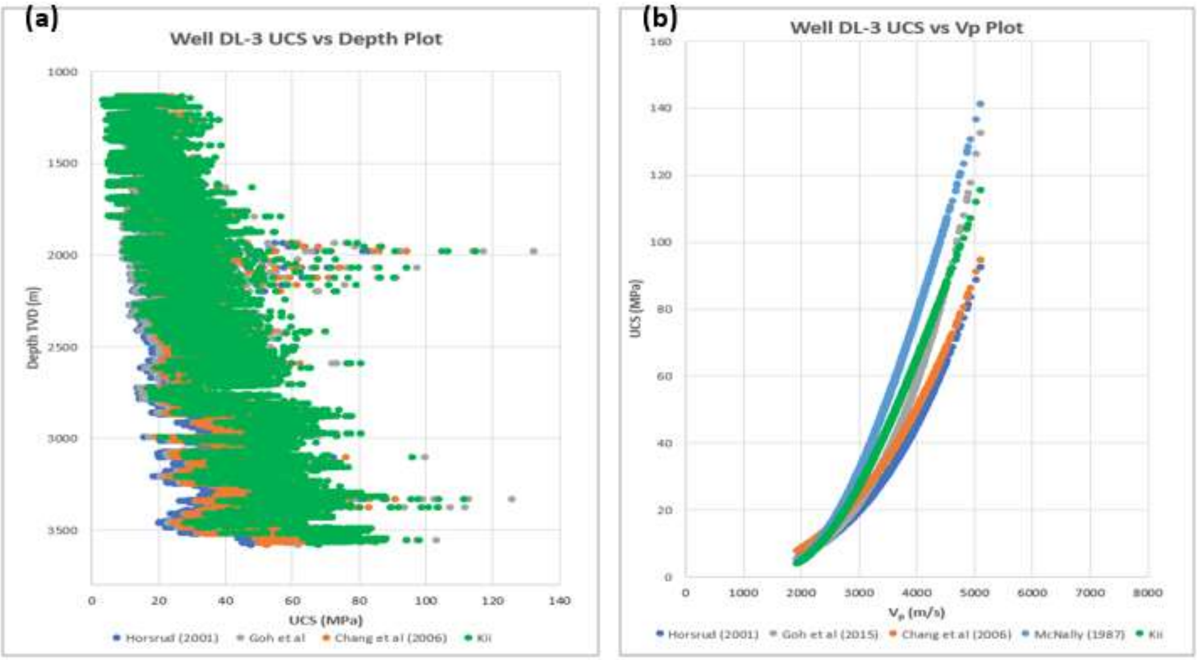


**Fig. 5: comparison of various models with the developed model for Well DL-3 (a) UCS vs depth plot and Shale Delineation, (b) UCS vs $V_p$ plot**

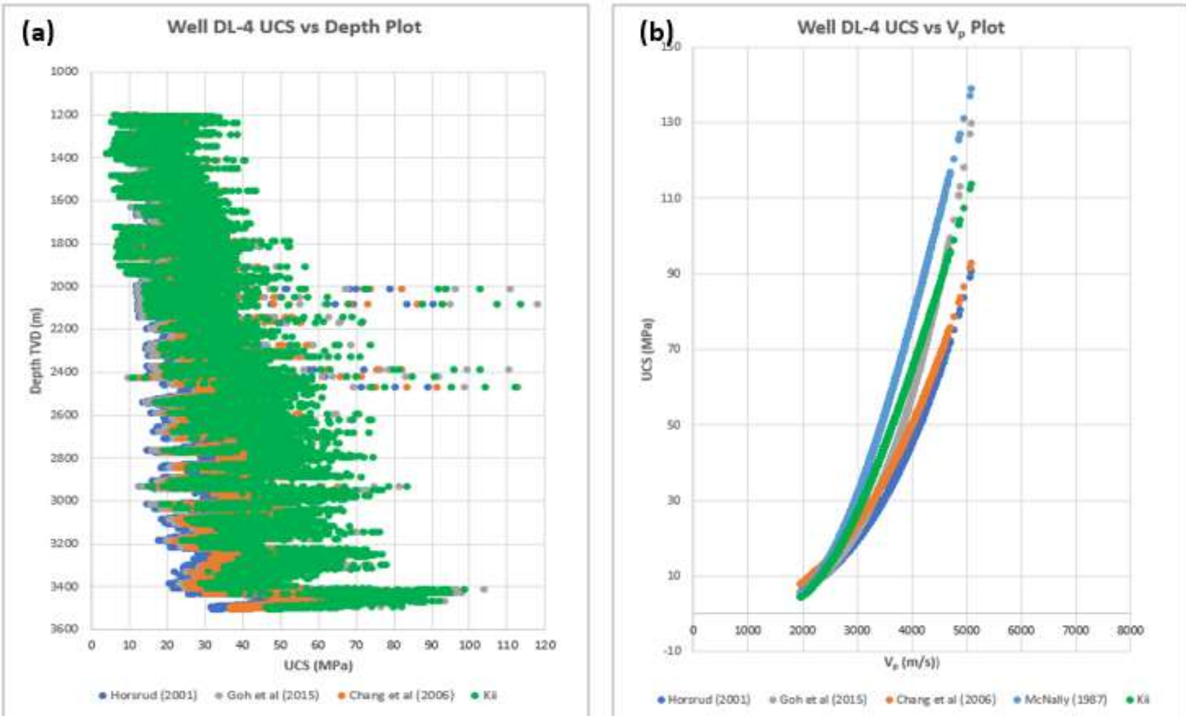


**Fig. 6: comparison of various models with the developed model for Well DL-4 (a) UCS vs depth plot and Shale Delineation, (b) UCS vs $V_p$ plot**

**Table 3: Statistical Analysis to Compare the developed Empirical Model with other Established UCS Equations (models)**

| UCS Equations | Mean ± SD |
|---|---|
| Horsrud (2001) | $14.81 \pm 8.57^{a}$ |
| Chang (2006) | $18.29 \pm 9.55^{b}$ |
| Goh (2015) | $20.40 \pm 10.76^{c}$ |
| McNally (1987) | $22.32 \pm 16.44^{d}$ |
| Developed model (Empirical Equation) | $19.06 \pm 13.76^{c}$ |
| P-value | <0.0001 |
| F-value | 2.372 |

Values with different superscripts are significantly different from each other ($P \leq 0.05$)

### 4.1 Geomechanical Properties for Well DL-1

In Well DL1, four (4) reservoirs were delineated. Compressional velocity, $V_p$ for the sandy intervals obtained were, 3.78, 4.03, 3.87 and 4.57 km/s for Sand 1, 2, 3 and 4 respectively as shown in Table 4. An increase in $V_p$ was observed based on the lithologic characteristics and the fluid content in this well. According to [11], saturated rock has higher $V_p$ when compared to the unsaturated rock. Sand 4 has a higher $V_p$ and equally saturated with hydrocarbon which is suggested to account for and higher value of $V_p$. The obtained compressional-Share velocity ratios ($V_p/V_s$), for the shaley intervals were, 2.01, 2.02, 2.02 and 2.03 for shale units 1, 2, 3 and 4 respectively. These results compare Favorably with [23], who's has observed that, clay or shales have $V_p/V_s$ ratio > 2.0. The results obtained for the shaley intervals in Table 4 have $V_p/V_s$ ratios exceeding 2.0. This result shows that $V_p/V_s$ ratio can be used as a complimentary tool for lithology identification and delineation in the study area.

The estimated UCS for the sandy intervals were, 55.18, 65.66, 58.62 and 89.67 MPa for sand 1, 2, 3 and 4 respectively. These results suggest that a higher force will be required to perforate the reservoirs of these intervals for maximum production of oil and gas. However, UCS for the shaley intervals ranges from 48.00 to 57.30 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 57.30 MPa will fracture the shale formations.

### 4.2 Geomechanical Properties for Well DL-2

In Well DL2, six (6) reservoirs were delineated. Compressional velocity, $V_p$ for the sandy intervals are 3.79, 3.99, 3.89, 3.91, 3.61 and 3.91 km/s for Sand 1, 2, 3, 4, 5 and 6 respectively as shown in Table 5. An increase in $V_p$ was observed was observed with the hydrocarbon intervals of sand 2, 4, 5 and 6. It was observed that sand 5 is hydrocarbon bearing but the $V_p$ value is low because of the sand-shale intercalation as observed. It is clear that a clean sand reservoir saturated with hydrocarbon has a higher $V_p$ value than clean sand reservoir bear water. These results are in agreement with the contributions of [11]. $V_p/V_s$ ratios for the shaley intervals are 2.02, 2.05, 2.01, 2.02, 2.02 for shale 1, 2, 3, 4 and 5 respectively. The results obtained for the shaley intervals in Table 5 have $V_p/V_s$ ratio that exceeds [20] threshold as discussed above. UCS for the sandy intervals are 3.79, 3.99, 3.89, 3.91, 3.61 and 3.91 for sand 1, 2, 3, 4, 5 and 6 respectively. These results suggest that a higher force will be required to perforate the reservoirs of these intervals for maximum production of oil and gas. However, UCS for the shaley intervals ranges from 31.10 to 48.49 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 48.49 MPa will fracture the shale formations.

### 4,3. Geomechanical Properties for Well DL-3

In Well DL-3 four (4) reservoirs were delineated. The obtained Compressional velocity, $V_p$ for the sandy intervals were, 3.81, 3.97, 3.99 and 4.17 km/s for Sand 1, 2, 3 and 4 respectively, this is shown in Table 6. The $V_p$ values observed in this well were in conformity with the higher values observed in the hydrocarbon levels in previous wells. These results are in agreement with the contributions of [11]. The obtained $V_p/V_s$ ratios for the shaley intervals were, 2.00, 2.01, and 2.02, for shale units 1, 2, and 3 respectively. The results obtained for the shaley intervals in Table 6 have $V_p/V_s$ ratio that exceeds the threshold of [20] as discussed above. The UCS values obtained for the sandy intervals of this well were, 56.29, 63.31, 64.26 and 71.14 MPa for sand units 1, 2, 3 and 4 respectively. These results suggest that a higher force will be required to perforate the reservoirs of these intervals for maximum production of oil and gas. UCS for the shaley intervals ranges from 44.61 to 55.01 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 55.01 MPa will fracture the shale formations.

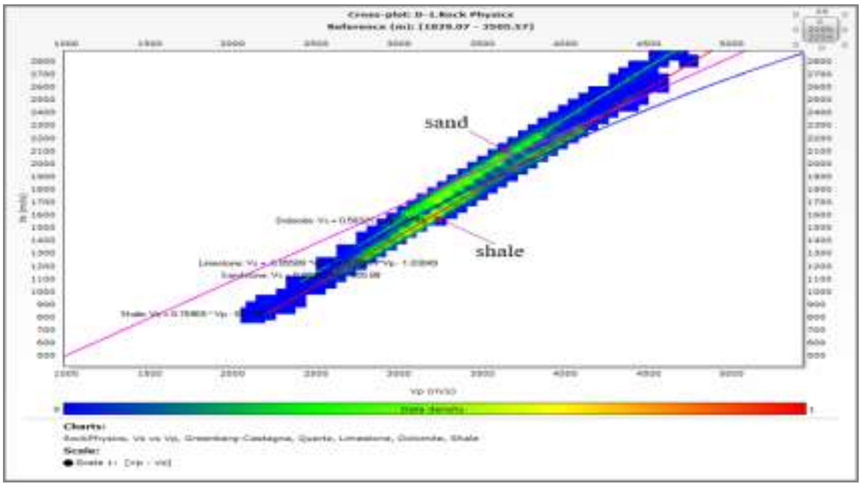


**Fig. 7: Reservoirs Shear Velocity Modelling Calibration for Well DL1 Greenberg-Castagna Shear Velocity Calibration,**

### 4.4. Geomechanical Properties for Well DL-4

In Well Dl-4 four (4) reservoirs were delineated. The obtained Compressional velocity, $V_p$ for the sandy intervals were, 3.79, 3.81, 3.87 and 4.20 km/s for Sand units 1, 2, 3 and 4 respectively as shown in Table 7. The $V_p$ values reported in this well is in conformity with the higher values observed in the hydrocarbon levels in previous wells. Sand 2, 3 and 4 are hydrocarbon bearing reservoirs. The compressional velocity ($V_p$) of Sand 4 was estimated as, 4.20 km/s with a gross thickness of 69.93m. from the GR log, the reservoir was observed to be clean resulting to a higher value of $V_p$. These results are in agreement with the contributions of [11]. $V_p/V_s$ ratios for the shaley intervals are 2.04, 2.02, 2.01, for shale 1, 2, and 3 respectively. The results obtained for the shaley intervals in Table 7 have $V_p/V_s$ ratio that exceeds the values recommended threshold in [20] as discussed above. UCS for the sandy intervals of this well were, 55.24, 56.18, 58.83 and 72.87 MPa, for sand 1, 2, 3 and 4 respectively. These results suggest that a higher force will be required to perforate the reservoirs of these intervals for maximum production of oil and gas. The UCS ranges from 39.99 to 45.02 MPa. These results suggest that any applied uniaxial stress during drilling that exceeds 45.02 MPa will fracture the shale formations.

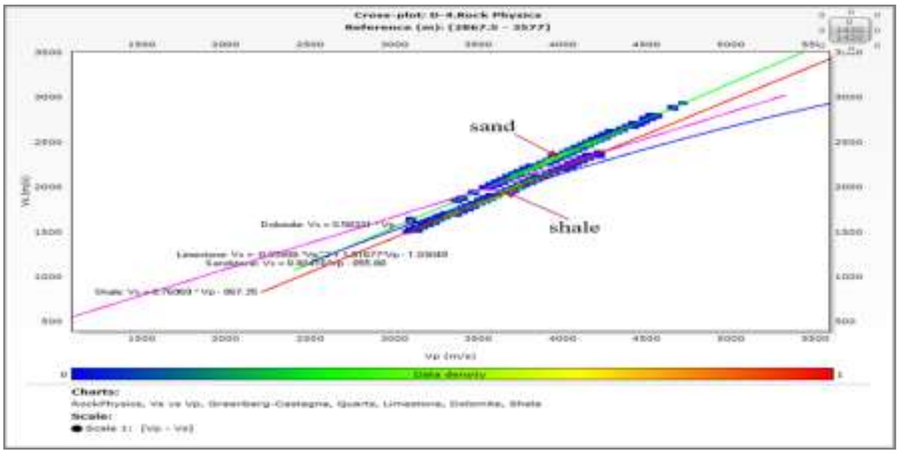


**Fig. 8: Reservoirs Shear Velocity Modelling Calibration for Well DL-2 Greenberg-Castagna Shear Velocity Calibration**

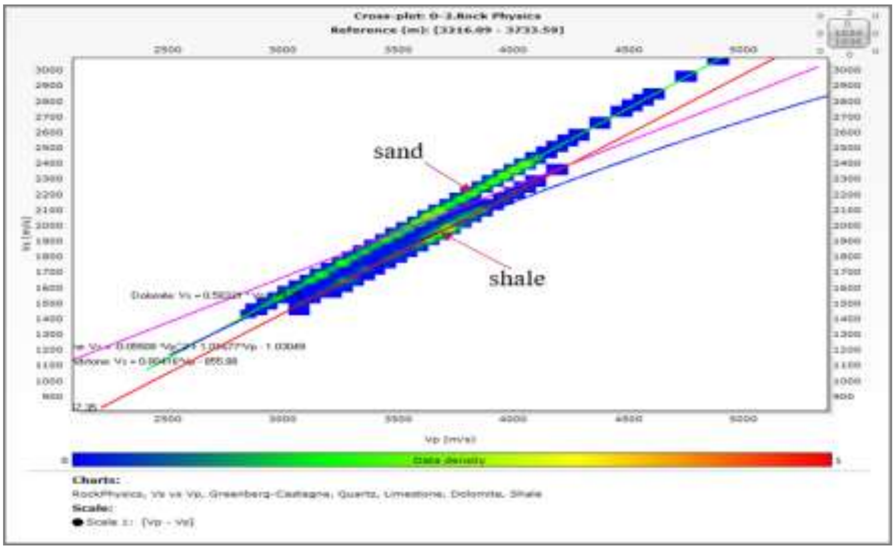


**Fig. 9: Reservoirs Shear Velocity Modelling Calibration for Well DL-3 Greenberg-Castagna Shear Velocity Calibration,**

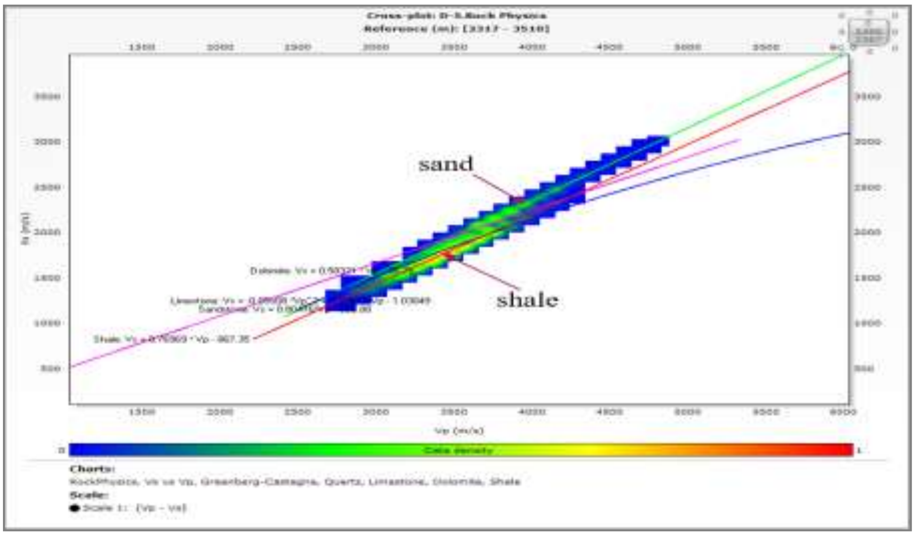


**Fig. 10: Reservoirs Shear Velocity Modelling Calibration for Well DL-4 Greenberg-Castagna Shear Velocity Calibration,**

**Table 4: Average geomechanical properties of rocks in Well DL-1**

| Zones | Top | Bottom | Gross | Vp | Vs | Vp/Vs | UCS |
|---|---|---|---|---|---|---|---|
| | m | m | m | Km/s | Km/s | unitless | MPa |
| **Sand 1** | 2877.12 | 2909.01 | 31.89 | 3.78 | 2.12 | 1.78 | 55.18 |
| **Shale 1** | 2909.01 | 2940.90 | 31.89 | 3.60 | 1.79 | 2.01 | 48.36 |
| **Sand 2** | 2940.90 | 2969.74 | 28.84 | 4.03 | 2.35 | 1.72 | 65.66 |
| **Shale 2** | 2969.74 | 3085.43 | 115.69 | 3.60 | 1.78 | 2.02 | 48.08 |
| **Sand 3** | 3085.43 | 3094.93 | 9.50 | 3.87 | 2.17 | 1.79 | 58.62 |
| **Shale 3** | 3094.93 | 3360.91 | 265.98 | 3.59 | 1.77 | 2.02 | 48.00 |
| **Sand 4** | 3360.91 | 3427.07 | 66.16 | 4.57 | 2.80 | 1.64 | 89.67 |
| **Shale 4** | 3427.07 | 3481.69 | 54.62 | 3.83 | 1.89 | 2.03 | 57.30 |

**Table 5: Average Geomechanical Properties of Rocks in Well DL-2**

| Zones | Top | Bottom | Gross | Vp | Vs | Vp/Vs | UCS |
|---|---|---|---|---|---|---|---|
| | m | m | m | Km/s | Km/s | unitless | MPa |
| **Sand 1** | 3226.56 | 3250.32 | 23.76 | 3.79 | 2.09 | 1.81 | 55.31 |
| **Shale 1** | 3250.32 | 3302.62 | 52.3 | 3.48 | 1.72 | 2.02 | 43.48 |
| **Sand 2** | 3302.62 | 3328.37 | 25.75 | 3.99 | 2.33 | 1.72 | 63.85 |
| **Shale 2** | 3328.37 | 3338.67 | 10.30 | 3.59 | 1.75 | 2.05 | 47.75 |
| **Sand 3** | 3338.67 | 3391.77 | 53.10 | 3.89 | 2.23 | 1.74 | 59.75 |
| **Shale 3** | 3391.77 | 3549.61 | 157.84 | 3.61 | 1.79 | 2.01 | 48.49 |
| **Sand 4** | 3549.61 | 3561.00 | 11.39 | 3.91 | 2.28 | 1.71 | 60.31 |
| **Shale 4** | 3561.00 | 3628.37 | 67.37 | 3.49 | 1.73 | 2.02 | 43.64 |
| **Sand 5** | 3628.37 | 3644.61 | 16.24 | 3.61 | 2.05 | 1.76 | 48.56 |
| **Shale 5** | 3644.61 | 3668.39 | 23.78 | 3.31 | 1.64 | 2.02 | 31.10 |
| **Sand 6** | 3668.39 | 3683.85 | 15.46 | 3.91 | 2.29 | 1.72 | 61.58 |

**Table 6: Average Geomechanical Properties of Rocks in Well DL-3**

| Zones | Top | Bottom | Gross | Vp | Vs | Vp/Vs | UCS |
|---|---|---|---|---|---|---|---|
| | m | m | m | Km/s | Km/s | unitless | MPa |
| **Sand 1** | 3134.97 | 3172.69 | 37.72 | 3.81 | 2.15 | 1.78 | 56.29 |
| **Shale 1** | 3172.69 | 3231.44 | 58.75 | 3.51 | 1.75 | 2.00 | 44.61 |
| **Sand 2** | 3231.44 | 3318.47 | 87.03 | 3.97 | 2.30 | 1.73 | 63.31 |
| **Shale 2** | 3318.47 | 3326.45 | 7.98 | 3.79 | 1.82 | 2.01 | 55.01 |
| **Sand 3** | 3326.45 | 3372.50 | 46.05 | 3.99 | 2.31 | 1.73 | 64.26 |
| **Shale 3** | 3372.5 | 3473.63 | 101.13 | 3.60 | 1.78 | 2.02 | 48.17 |
| **Sand 4** | 3473.63 | 3553.73 | 80.12 | 4.17 | 2.47 | 1.68 | 71.14 |

**Table 7: Average Geomechanical Properties of Rocks in Well DL-4**

| Zones | Top | Bottom | Gross | Vp | Vs | Vp/Vs | UCS |
|---|---|---|---|---|---|---|---|
| | m | m | m | Km/s | Km/s | unitless | MPa |
| **Sand 1** | 3019.40 | 3048.36 | 28.96 | 3.79 | 2.14 | 1.78 | 55.24 |
| **Shale 1** | 3046.36 | 3125.12 | 78.76 | 3.44 | 1.68 | 2.04 | 41.94 |
| **Sand 2** | 3125.12 | 3139.60 | 14.48 | 3.81 | 2.15 | 1.78 | 56.18 |
| **Shale 2** | 3139.60 | 3208.96 | 69.36 | 3.39 | 1.68 | 2.02 | 39.99 |
| **Sand 3** | 3208.96 | 3273.09 | 64.13 | 3.87 | 2.20 | 1.76 | 58.83 |
| **Shale 3** | 3273.09 | 3392.63 | 119.54 | 3.52 | 1.75 | 2.01 | 45.02 |
| **Sand 4** | 3392.63 | 3462.56 | 69.93 | 4.20 | 2.49 | 1.69 | 72.87 |

## V. Conclusion

A new model (an empirical Equation) has been developed in this study, from well logs, to estimate UCS from Compressional Velocity ($V_p$), for the Northern Depobelt of Onshore Niger Delta. The developed empirical Equation is UCS = 924.46*exp(-0.035DT$_p$) with a coefficient of determination ($R^2$) of 0.98. Determination of UCS from this developed empirical Equation is simple and less time consuming as $V_p$ was calculated from sonic log. Assessment of rock strength is crucial for well planning, drilling and perforation operations wellbore stability, subsidence, or surface deformations, changes in reservoir pressure, fluid movement, or compaction, processes such as tectonic movements, faulting or volcanic activity because it provides better insight in the geomechanical properties of the rock which can be used to detect these anomalies. Thus, this Equation is suggested to be useful for the purpose of determining rock strength for drilling operations, geopressure analysis, compaction trend determination and perforation operations in

## VI. References

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