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The Constants of Density-Velocity Relation for Density Estimation in Tau Field, Niger Delta Basin

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Abstract: *Well-log data covering three wells (AA, BB and CC) in Tau($\boldsymbol{\tau}$) Field in the Niger Delta were used for density-velocity constants evaluation. Using Hampson Russell Software, Gardner's and Lindseth's relations were localized and subsequently transformed to obtain the local fits constants: b, n, e and f for sand and shale lithologies. The correlation result of V_p with V_s is 0.93 which is a strong linear relationship; therefore, density can also be predicted using shear wave velocity data. The major findings resulting from the local fit for sands and shales differentiated, indicate b and n from compressional wave velocity as 0.23 and 0.27 (from shear wave velocity as 0.12 and 0.24) respectively for sand; 0.52 and 0.45 (from shear wave velocity as 0.23 and 0.30) respectively for shale. Also, the constants e and f from compressional wave velocity as 0.320 and 3481 (from shear wave velocity as 0.340 and 1640) respectively for sand; 0.35 and 1595 (from shear wave velocity as 0.35 and 8380) respectively for shale.*

Keywords: *Density, Velocity, Constants, Sand, Shale, Lithology and Well-Log Data.*

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I. Introduction

Density values overlap for sands and shales (with shales velocity lesser than that of sand). This makes density not a good lithological indicator. This property aids in identification of reservoir rock by lithology delineation; it is also useful in the detection of gas-bearing formations, the identification of evaporates and in ore content evaluation for mining activities (Keareyet al., 2002).It is used by Geoscientists and Reservoir Engineers to quantify and model reservoirs since it is a measure of reservoir quality in both clastic and carbonate rocks.

In order to obtain different density-velocity relations and their parameters, p-wave velocity, s-wave velocity, density and gamma ray data from a well can be used (Quijada& Stewart, 2007).Well-logs are used to determine velocity-density balances with Gardner-Lindseth connection aimed at valuing density.

Crossploting density with rock properties, lithology and pore fluid indicate density as the property that gives the best differentiation between hydrocarbon reservoirs and other fluid types (Koughnetet al., 2003). This makes accurate density estimates significant for characterization of reservoir. By Grayet al.(2006), a proper estimate of density is required to determine the shale locationwhich may prevent the steaming or recovery process.

Location and Geology of the Study Area

τ Field is located 40km southwest of Port Harcourt, Rivers State in the Niger Delta within latitudes 3^0N and 6^0N; longitudes 5^0E and 8^0E (Figure 1). Niger Delta is characterized with two distinct seasons: Wet season (March till October) and dry season (November till February). The mean monthly rainfall during rainy season is about 135 mm and this falls to 65 mm during dry season (Atat, et al., 2012; George et al., 2010).

From the period of Eocene to the present, the delta has advanced towards the south, forming depobelts that stand for the most engaging portion of the delta at each stage of its development (Doust&Omatsola, 1990). These depobelts(Figure 1) form one of the deltas which is characterized by regression and it is the largest in the world with an area of 300,000 km^2 (Kulke, 1995); sediment volume of 500,000 km^3 (Hospers, 1965); sediment thickness of over 10 km in the basin depocenter (Kaplan et al., 1994). Niger Delta province contains only one identified petroleum system called the Tertiary Niger Delta (Akata-Agbada) petroleum system. The rock from primary source is the upper Akata formation. Oil is produced from sandstone facies within the Agbada formation; the main target is the turbidite sand located in the upper Akata formation in deep water offshore or may be onshore (Tuttle, et al., 1999; Kulke, 1995; Ekweozor&Daukoru, 1994). The formation has an estimate of up to 7 x 10^3 metres thick (Doust&Omatsola, 1990). The Benin formation is about 0.28 x 10^3 metres thick but may be up to 2.1 x 10^3 metres in the region of maximum subsidence (Whiteman, 1982), and consists of continental sands and gravels.

Figure 1: Niger Delta Study Area with Base Map.

Source: Kulke (1995)

Theoretical Basis

The laws of Physics are applied to determine the distribution of reservoir fluids (gas, oil and water) trapped in a reservoir. Gardner et al., 1974 and Lindseth, 1979 have modelled density-velocity expressions for density estimate in their area of study. Their parameters could not give accurate prediction in the τ Field or any other field in the Niger Delta basin since this basin was excluded in their study.

According to Gardner's relation:

$$\rho = aV_p^m \qquad 1$$

where aandm are Gardner's default parameters (constant coefficients); ρ is the bulk density; V_p is compressional wave velocity.

This relation is a good approximation for shales, sandstones and carbonates while coals and evaporates depart significantly from the expected behaviour (Gardner et al., 1974; Quijada and Stewart, 2007).

If equation 1is localized to a parameter in our field of interest using b and n as constant coefficients for local fits. The expression becomes

$$\rho = bV_p^n \qquad 2$$

Taking the log of both sides of equation 2 and applying the laws of logarithm

$$\log\rho = \log b + n\log V_p \qquad 3$$

A plot of $\log\rho$ versus $\log V_p$ enables the deduction of b and n from the antilog of the intercept and the slope of the graph respectively.

From Lindseth's relation (or equation),

$$V_p = c\rho V_p + d \qquad 4$$

(Lindseth, 1979).

Considering it for the local fits constants for sand and shale, yields

$$V_p = e\rho V_p + f \qquad 5$$

$$\rho = \frac{V_p - f}{eV_p} \qquad 6$$

where eand f are local fit constants from least square fit approach; c and d are Lindseth's constants.

The use of special software (Hampson Russell) enables the crossplots that lead to achieving our purpose.

II. Materials and Methods

Materials

Hampson Russell Software was used for data loading, processing, crossplots and diagrams. Data acquired from the onshore Niger Delta oilfield are suites of Logs from three wells (Figures 2), markers,base map (Figures 1) and geology.

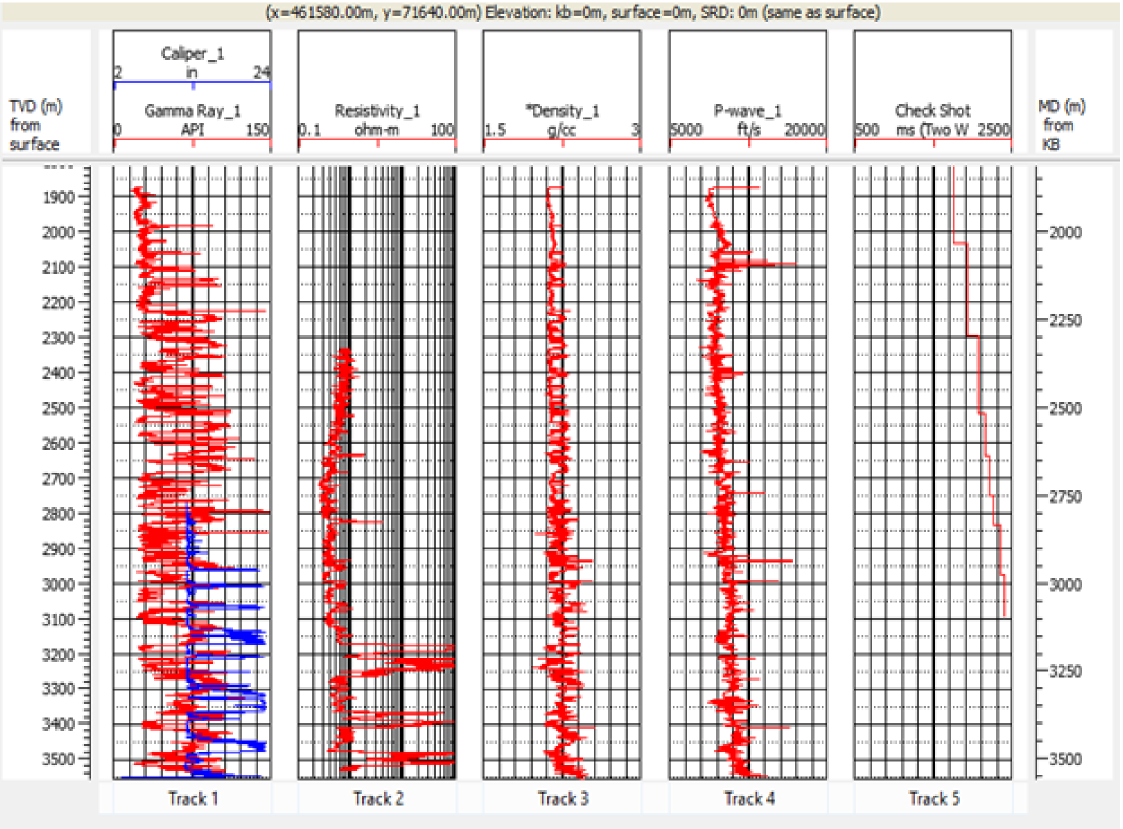

Figure 2.0: Suite of imported logs showing log signatures of Gamma ray, Resistivity, Density and P-wave velocity.

Method

The log Import interface of the Hampson Russell Software (HRS) was used to import well data, tops applied, consistency of wellbore diameter checked with caliper log, the section of the log which was compromised edited out which results in figure 3 and other procedure stated in figure 4 lead to the estimation of these parameters.

Figure 4 breaks down the well-log analysis carried out to determine the reservoir zones, estimation of rock attribute (the s-wave velocity was generated from p-wave velocity information); performed crossplots analysis to estimate the parameters for local fits.A linear regression line that best fits the data in a least-squares sense was applied to these relationships to estimate the coefficients b and n from equation 3; e and f from equation 5 for sand and shale lithology.

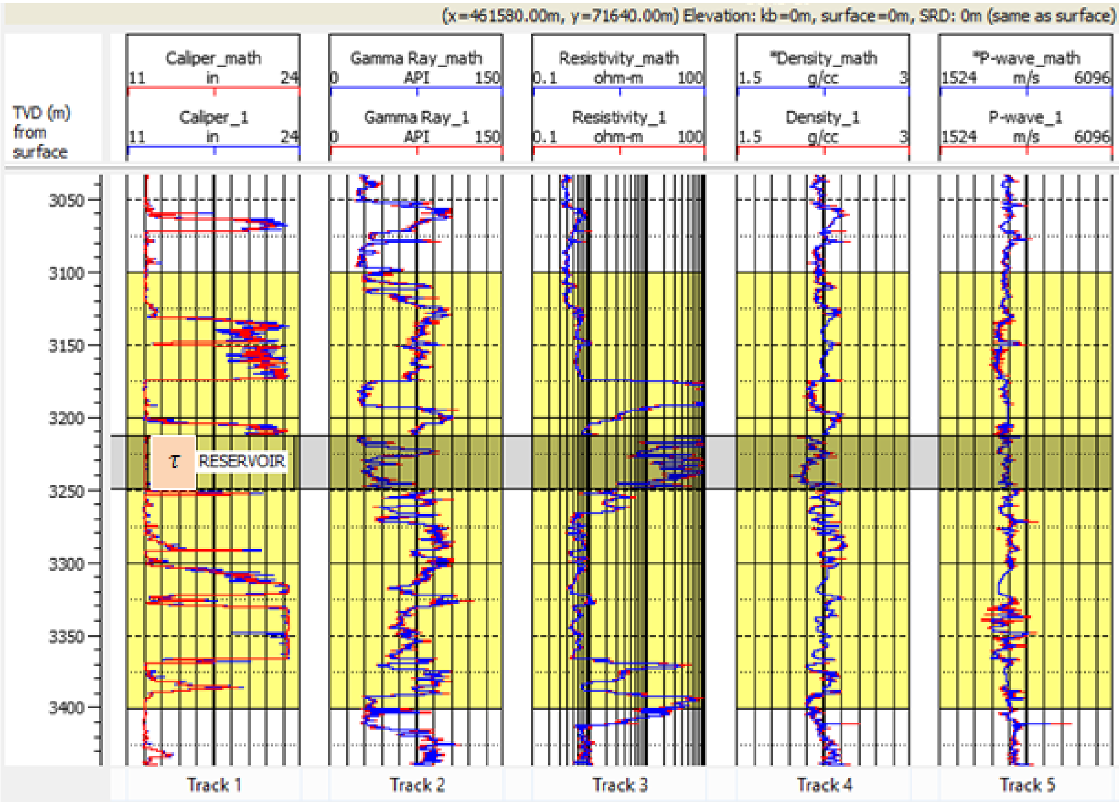

Figure 3: De-spiking of V_p, ρ and other logs using log filtering utility of HRS (filtered logs in blue, unfiltered logs in red).

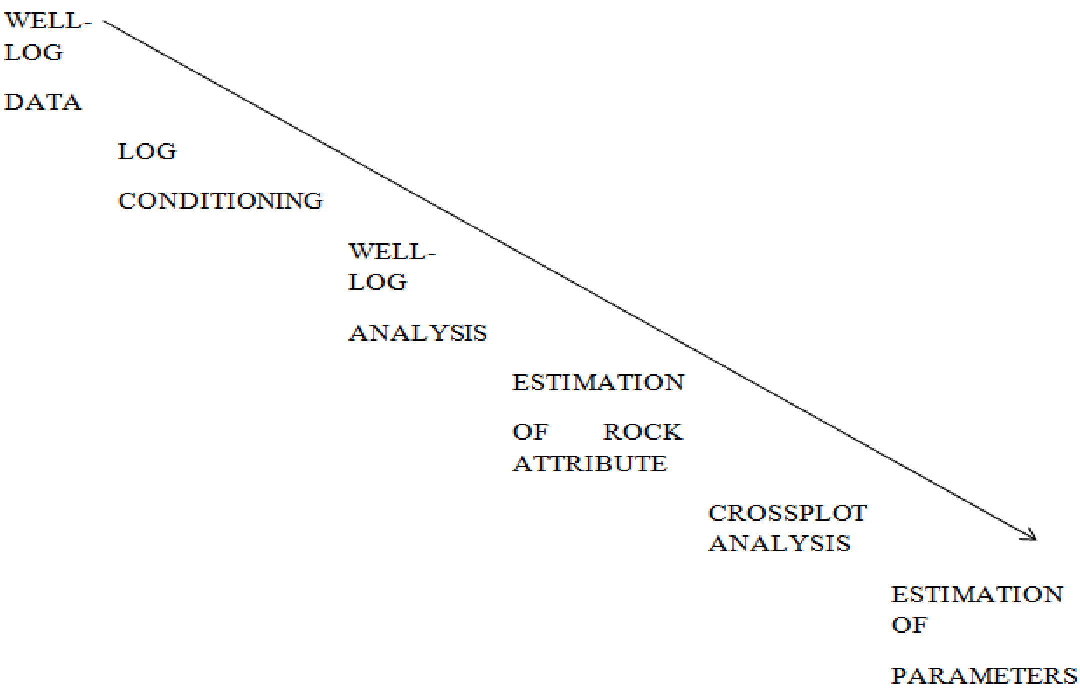

Figure 4: Workflow of Approach

III. Results and Discussion

Three wells of τ Fieldwere analyzed to obtain constants for density-velocity relations; the results are presented in Figures 5 to 9 and Tables 1.

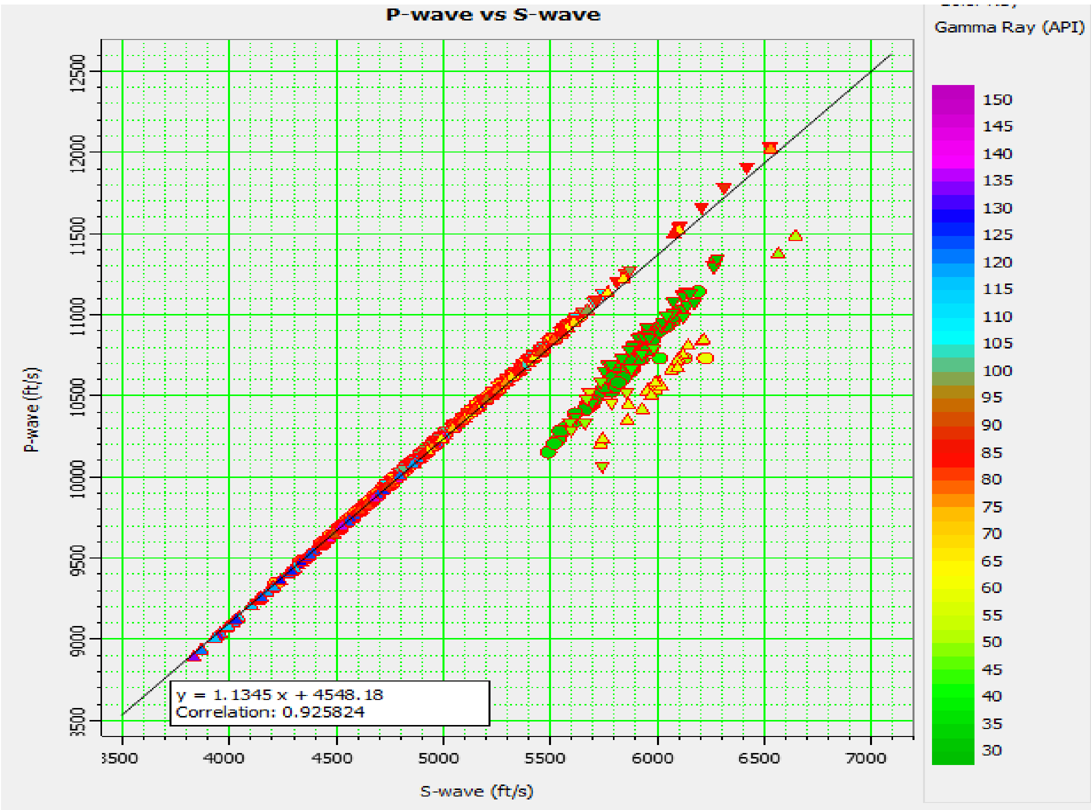

Figure 5: Correlation of V_p with V_s estimated using castagna's relation from the three wells

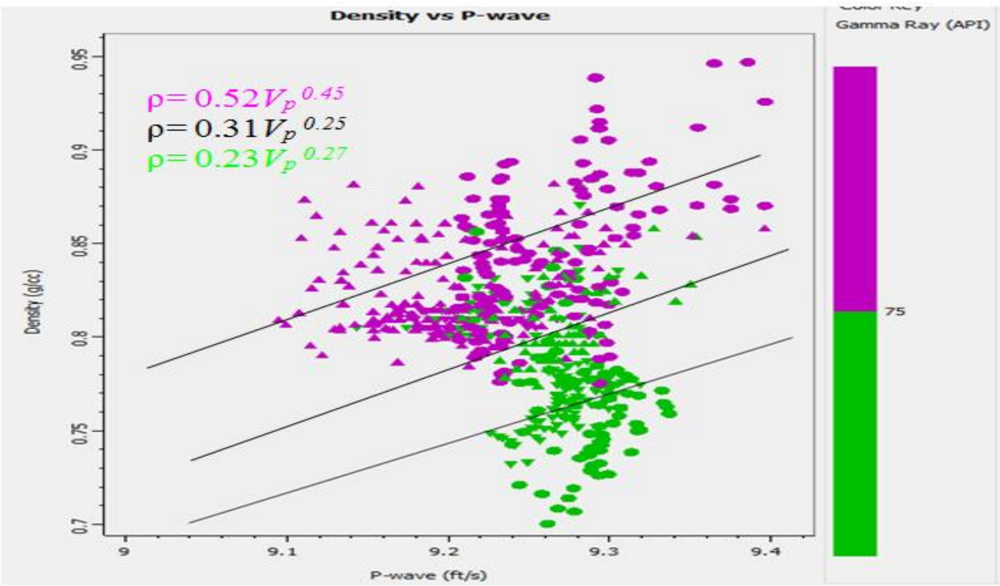

Figure 6: A plot of density versus V_p data for wells constants for sands (green) and shales (pink) with linear curve fitting using Gardner approach.

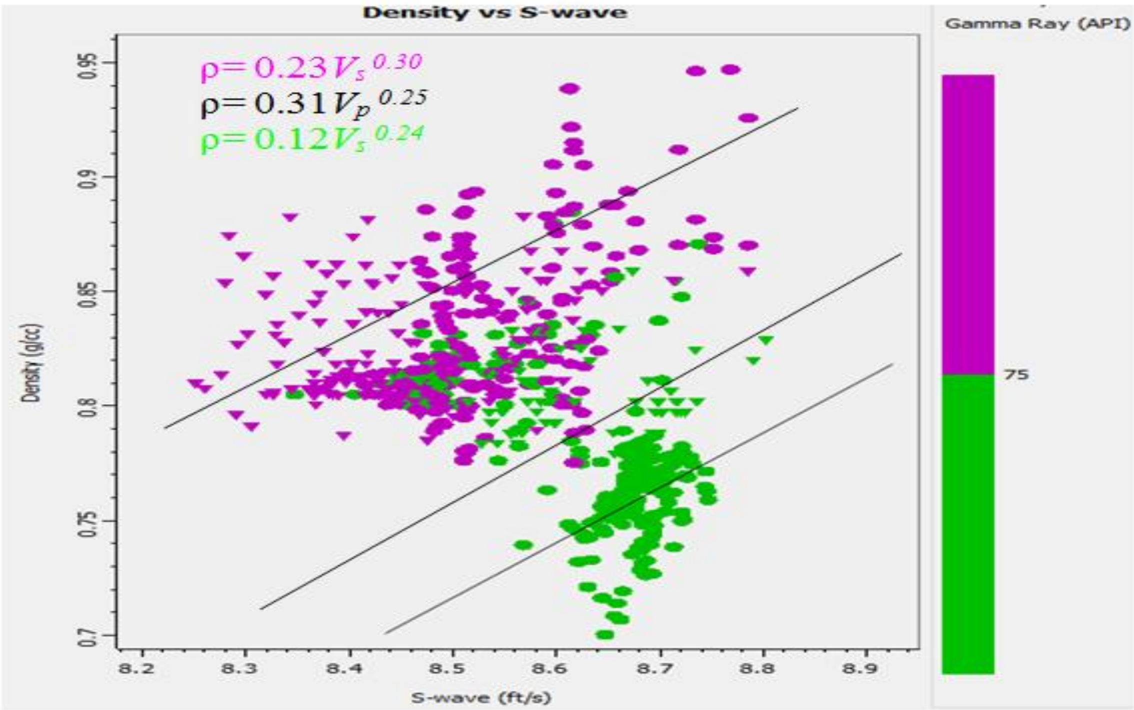

Figure 7: A plot of density versus V_s data for wells constants for sands (green) and shales (pink) with linear curve fitting using Gardner approach.

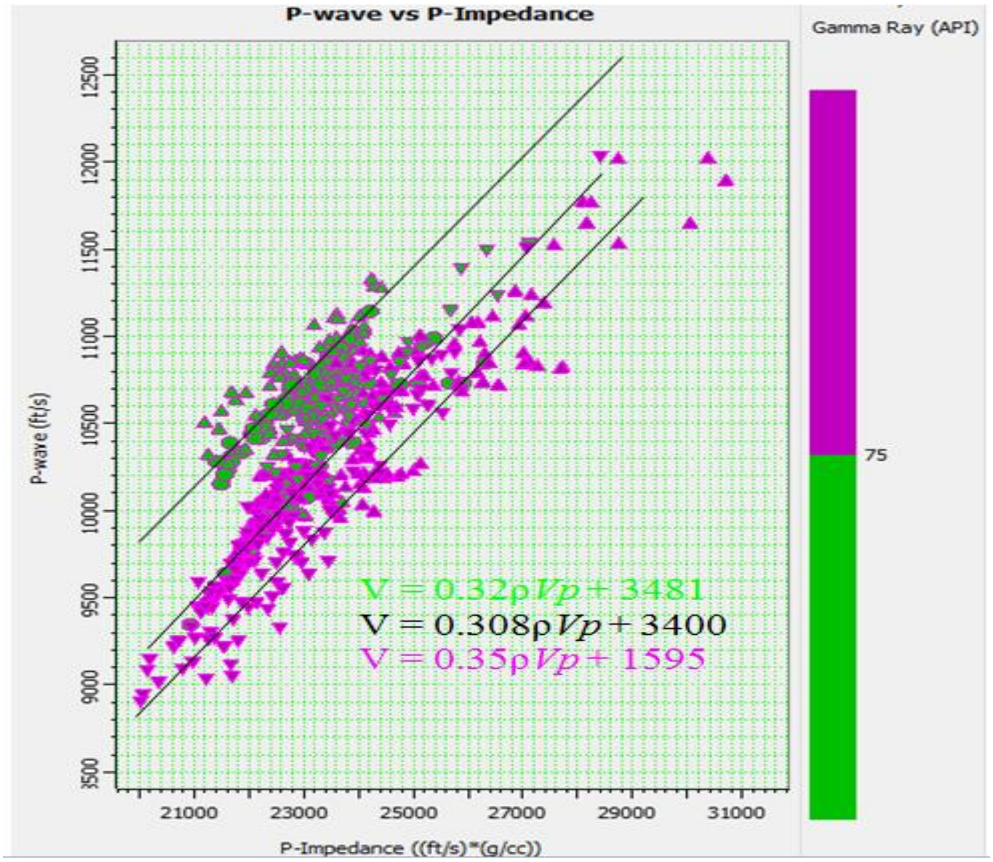

Figure 8: A plot of V_p versus p-impedance data for wells constants for sands (green) and shales (pink) with linear curve fitting using Lindseth approach

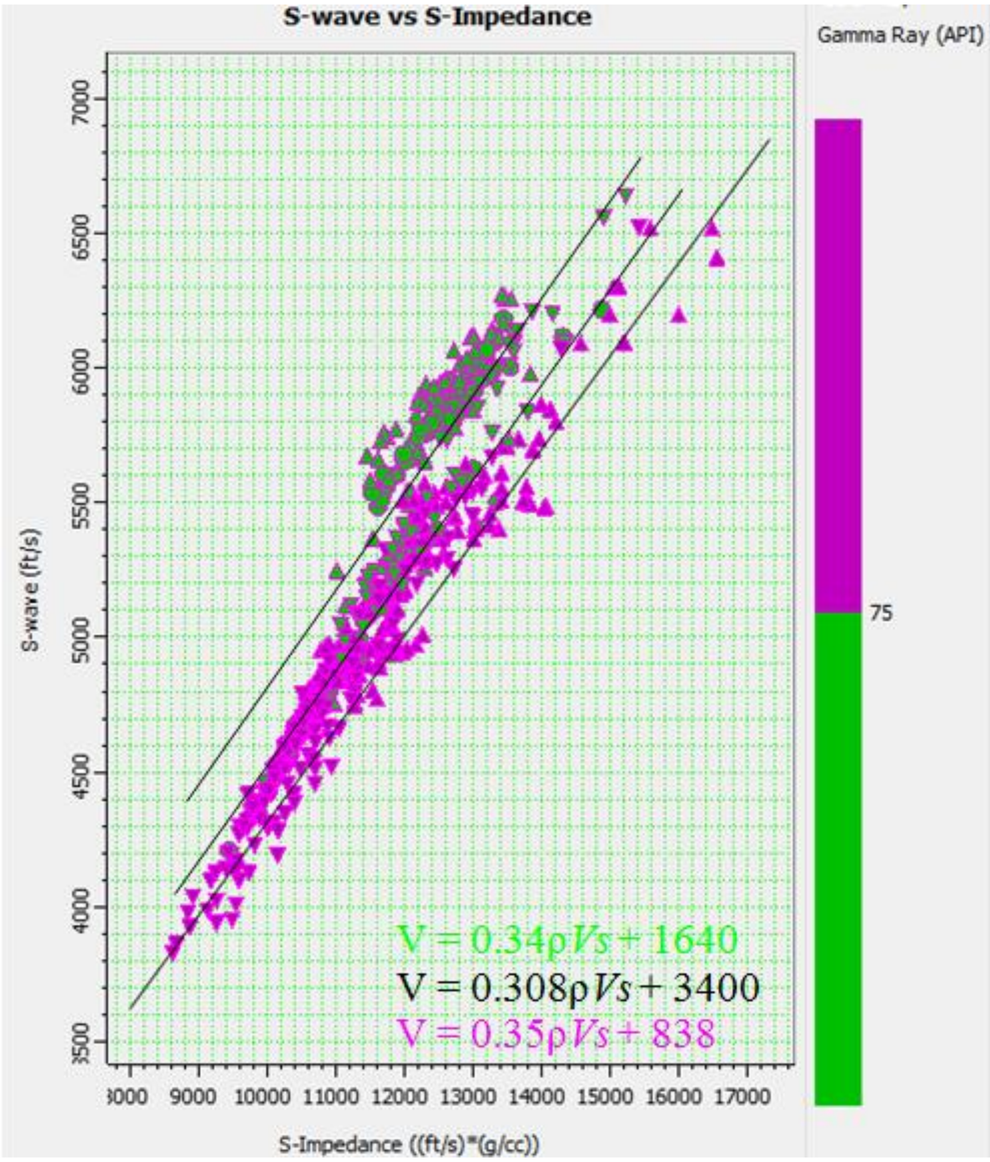

Figure 9: A plot of V_s versus s-impedance data for wells constants for sands (green) and shales (pink) with linear curve fitting using Lindseth approach.

Table 1:Estimated Constants (sands and shales) for Density Models.

Constants	Lithology Sand from V_p	Sand from V_s	Shale from V_p	Shale from V_s
b	0.23	0.12	0.52	0.23
n	0.27	0.24	0.45	0.30
Gardner's default: b = 0.31 and n = 0.25				
e	0.320	0.340	0.350	0.350
f	3481	1640	1595	838
Lindseth default: e = 0.308 and f = 1054				

Discussion

Shear wave velocity was achieved using Castagna's relation; the result was confirmed by investigating how strongp-wave velocity relateswith s-wave velocity as seen in figure 5. The correlation of 0.93 is very strong; the two parameters are linearly related.

The Gamma Ray (GR)as a lithology discriminator was used to aid the estimation of values of b and nfor specific rock types by considering the graph of density versus velocities with samples in green having GR lower than 75 which is for sands; samples in magenta have GR higher than 75 which is for shales(figures 6 and 7). These two clusters are now clearly differentiated, though very little overlap still exists between the samples. The fit is significantly improved by using this separation, with less dispersion of points with respect to the fitted line and coefficients closer to those defined by Gardner (This is from localized Gardner methodology). The new constants for local fits were obtained (Table 1).

The GR used to estimate values of e and ffor specific rock types was with respect to the graph of velocites versus impedances with samples in green having GR lower than 75 which arefor sands (Figures 8 and 9). The same cut-off of GR lower than 75 for sands (green); GR higher than 75 for shales (pink)with linear curve fitting using Lindseth approach was noted.

IV. Conclusion

Gardner's and Lindseth'srelationshipswere employed and localized to obtain constants for specific rock types. Shear wave velocityV_s was generated fromV_p; correlated with each other to investigate their relation strength; the result shows, they are strongly related.Gardner and Lindseth developed their constants with only P-wave data; we have obtained the constants for sand and shale for τfield using both P-wave and S-wave velocities from well-log data. This is different from their default parameters. Both researchers did not carry out their coefficients investigation for this field since it was not among their area of interest; as such do not give accurate constant for density estimation in the τ field or any related field in the Niger Delta.

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