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Research Article

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Comparative Analysis of Gardner's Relation in Lithology Discrimination for Density Modelling in the Niger Delta

Emudianughe J.E., Ahmad M.M.

Department of Earth Sciences, Federal University of Petroleum Resources, Effurun, Nigeria
Corresponding author: emudianughe.juliet@fupre.edu.ng

Abstract Density is an important parameter in reservoir characterization that can be used to differentiate lithologies and estimate other petrophysical parameters like the fluid content and porosity of a formation. Unavailability of density values or poor density logs creates problems for the reservoir engineer. The Gardner's equation is used to generate density values using primary or secondary waves velocities but its default parameters do not always lead to accurate results due to the inhomogeneity of the earth. This work tends to improve the accuracy of the Gardner's equation to predict density in the Niger Delta by modifying the parameters. The findings in this work will help in generating good density signatures in wells where density log data is unavailable. Density, gamma ray, P-wave and S-wave sonic log data from wells **REGO 10** and **REGO 11** in the Delta were used to evaluate the accuracy of the Gardner's relation in estimating density values that are used for lithology discrimination. Default values for ***a*** and ***m*** in the Gardner's equation are **0.31**(**0.23** when Vp is in Kms^{-1}) and **0.25**. The gamma ray log was used to differentiate the lithologies into shale and sand in the formation, from where a local fit to the gardner's coefficients were generated and assigned to the sands and shales resulting in values of **0.22** and **0.23** for ***a*** and ***m*** in sand respectively and **0.52** and **0.20** for shales. These values were used to estimate density in the respective formation using Gardner's relation. Default Gardner's parameters were also used to estimate density for the same formation. The two density models were overlain separately with the original density log from the wells. The density model with modified Gardner's parameters for different lithologies proves more accurate. Cross-plots of the estimated density logs from the modified gardner's equation with P-wave velocity also shows that the density estimate obtained with specific Gardner's parameters serves as a better lithology indicator.

Keywords Gardner, Crossplot, Density, Lithology, Parameters

Introduction

The prediction of density is a major goal in petroleum exploration. The knowledge of density helps in indicating the different lithologies and estimating other petro physical properties, such as porosity or fluid content. Density can also provide essential information for delineating a reservoir, of planning the position of a new or injecting well. Petrophysical analysis shows that the bulk density is an important acoustic indicator for indicating the presence of shale. In the case of oil sands and heavy oils, accurate estimates of density are necessary to determine the location of shales in the reservoir, the existence of which may interfere in the hydrocarbon recovery process. Cross-plots between rock properties and lithologies and pore fluid indicates that density provides the best differentiation between hydrocarbon reservoirs and other rock fluid type [1], therefore making accurate density estimates of importance to reservoir characterization. Since seismic method is one of the most important methods in exploration and is dependent on velocities of wave in rocks, finding a relationship between these velocities and rock densities is of utmost importance because it harmonizes the reservoir characterization process. Well logs are used to evaluate different density-velocity equations for estimating density from both V_S and V_p [2].

Density can be estimated from seismic data by seismic inversion (i.e AVO or waveform inversion) or by geostatistical methods where linear (multilinear regression) or non-linear relationships can be established between the rock properties (calculated at the well location), and the seismic data or a specific seismic attribute. Estimating density values from seismic data and modeling it remains an elusive task, as the inverse problem is ill posed, with a small change in the data resulting in a large change in the solution. Generally, Vs and Vp can be estimated reasonably from seismic inversion. However, inversion for a third parameter such as rock density is unstable, requiring the inclusion of a constrained on the parameters, which is usually by introducing a density-velocity relation to stabilize the inversion. The parameters on this density-velocity relation must be specifically accurate in estimating density from velocity values for the inversion to be accurate and useful. Density is important in exploration activities, specifically in reservoir characterization as it has relations to almost all petrophysical properties of rocks that includes porosity, fluid content, water saturation and hydrocarbon zones hence this research work is important as it enhances the overall process of reservoir characterization.

There are many empirical relationships that describe $V_p$as a function of density, but very few that compare V_s with densities. The fundamental empirical relationship between density and velocity was formulated as given in equation 1 [3]:

$$V_p = a + b\rho \quad (1)$$

Where a and b are empirical parameters and Vp is in Kms^{-1} and $\rho$is in gcm^{-3}.

Equation (1) becomes the basics for many other linear regression analyses. Further empirical relations found that the mineral composition of most rocks affect both the velocity and density in the same direction giving a correlation between them.

Gardner et al., [4] carried out a series of controlled filled and laboratory measurement of saturated sedimentary rocks and determined a relationship between Vp and density that has long been used in seismic analysis as given in equation 2:

$$\rho = aV^b \quad (2)$$

Where $\rho$is in gcm^{-3} and a=0.31 (if V is in ms^{-1}) or a=0.23 (if V is in fts^{-1}) and b=0.25.

Lindseth [5] used Gardner's empirical data to derive the following relationship between acoustic impedance and velocity as shown in equation 3:

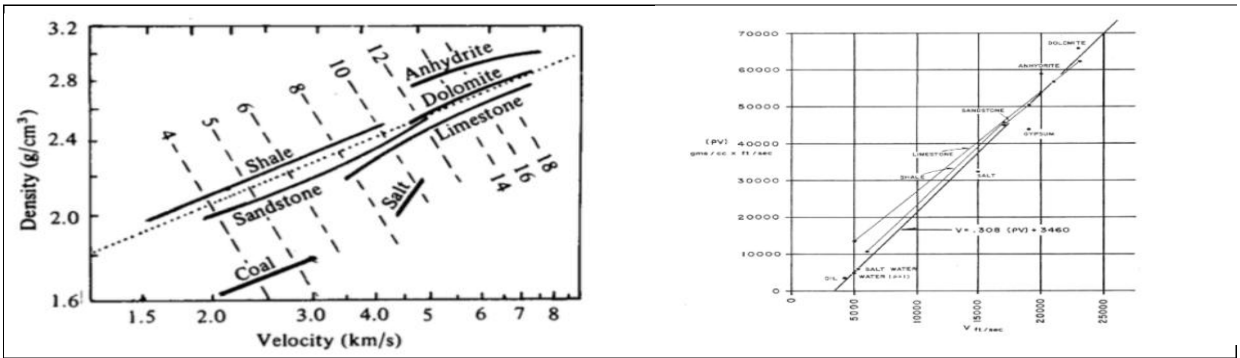
$$\rho V = \frac{V - C}{0.308} \quad (3)$$

Where ρ is in gcm^{-3}, and V=fts^{-1}, C=3460(1054 when V=ms^{-1})

Lindseth's results found out that detailed velocity measurements could be used to predict rock types. Well logs are used to evaluate different density-velocity equations, including Gardner's and Lindseth's relationship for estimating density, both from Vs and Vp. The relationship between wave velocity and Sonic log readings is:

$$V(ms^{-1}) = (1000000 * 0.305)/\Delta t \quad (4)$$

where Δt is the interval transit time in µsec/ft.



(A) (B)

Figure 1:A) Density versus P-wave velocity (Log-log scale). Gardner's empirical relationship where the dotted lines pertains to the Gardner's equation. B) Values of acoustic impedance versus rock velocity. Lindseth's relationship where the dotted line pertains.

Over the years, numerous authors have further investigated the applicability of Gardner’s and Lindseth’s relationships to a wide range of sedimentary rocks using both the Vp and Vs. The Vp generally gives good estimates of density from both equations but research works have not quite achieved a considerable level of success with the use of the Vs. Castagna et al., [6] suggest the use of different values of the coefficients a and m in the Gardner’s equation. Quijada and Stewart [2] found that using a local fit for sand and shales results in values of a and m of 0.51 and 0.19 for shales, 0.22 and 0.28 for sands respectively.

Methodology

Estimated density logs data generated from selected wells in the Niger delta were used to differentiate lithology using both the AVO modelling and Petrel software. The estimated density log was used together with the original density log and other well logs to designate zones of different lithologies. The well logs data were first quality-checked based on the loggers engineers observation.

The logs used in this work were selected because they have dipole sonic logs, the density used are bulk densities. The Hampsell-Russel AVO program was used to model for synthetic density log, generate cross-plots diagrams, graphs and estimated Gardner’s coefficients. Vp values were used to compute Vs values using the Castagna’s relation and density values using the Gardner’s relation and the corresponding variables a and m. The cross-plot program on AVO was used to get a Density-Vp cross-plots with the intercept being the parameter a and slope m coefficients respectively of the best line fit. The AVO function regression was used to find the coefficients of the polynomial that best fits the data in a least square sense.

The estimated density log was overlaid with the original density log and their correlation was used to indicate zones of different lithology.

The density-Vp cross plot was used to confirm the zones of different lithology as inferred by the densities overlay. The Gamma ray was used as a support for this lithological separation. Based on this, the gamma ray log was used as a lithological discriminator, to estimate values of a and m for different rock types. Samples with gamma ray values greater than 70 API were considered shales while those below 70 API were considered sands. This differentiation made it possible for density-Vp cross-plot to clearly distinguish zones of different lithology.

Results and Discussion

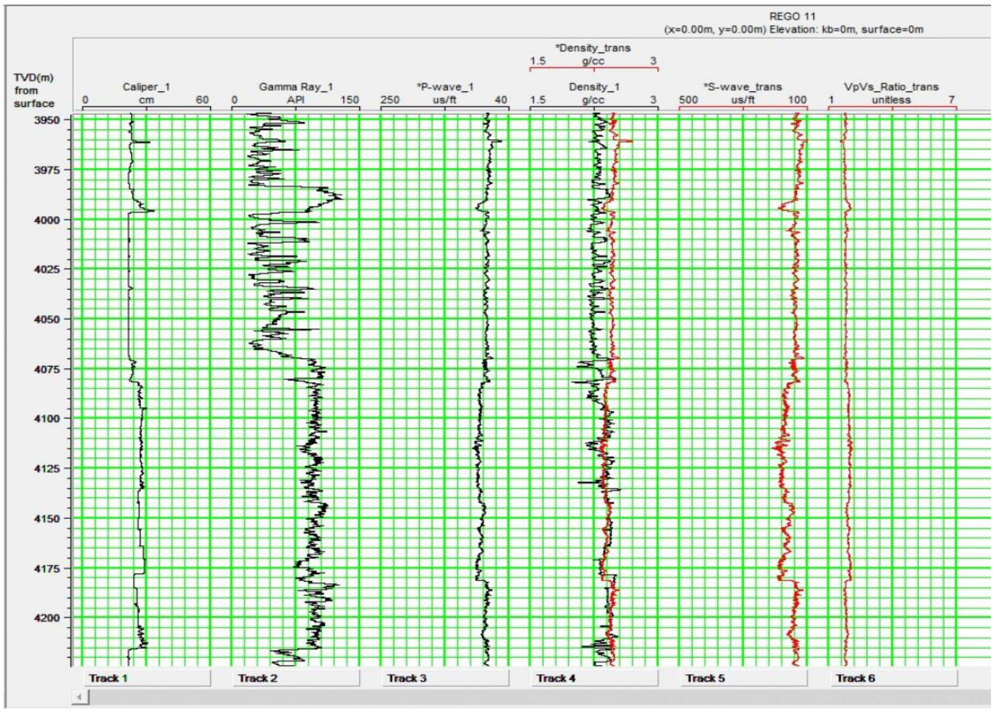


Figure 2: Well logs from well REGO 11 with synthetic density log overlaid with density log. The synthetic density log was computed using normal Gardner’s parameters

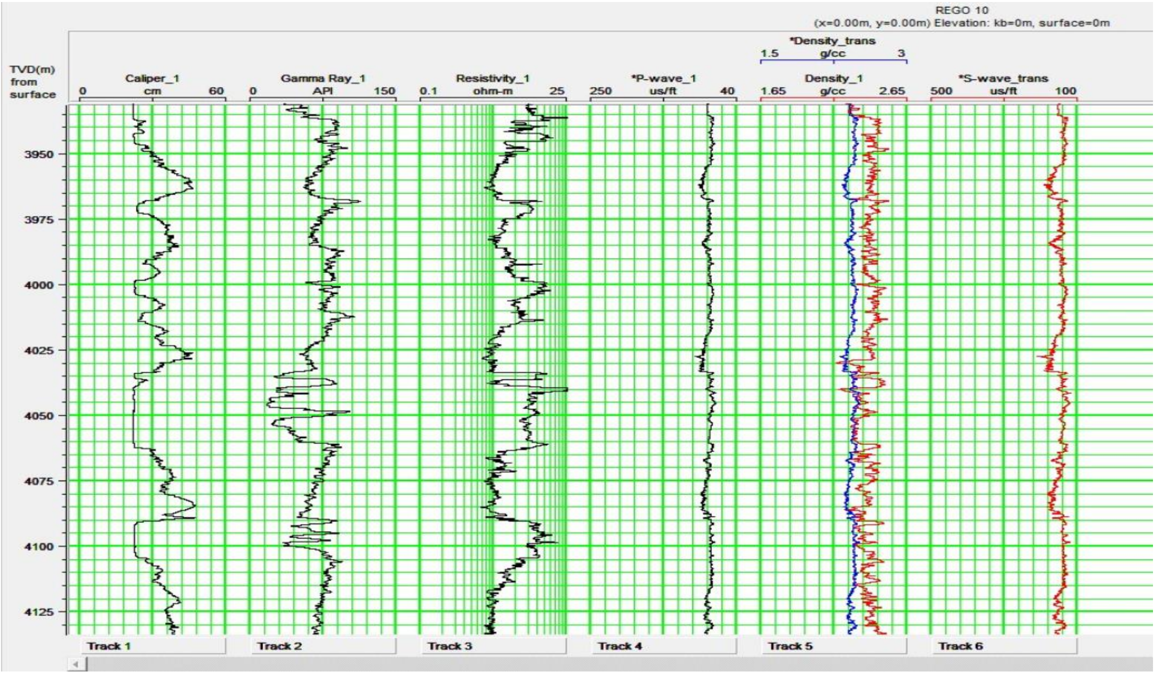


Figure 3: Well logs from Well REGO 10 with synthetic density log overlaid with density log. The synthetic density log was computed using default Gardner's parameters

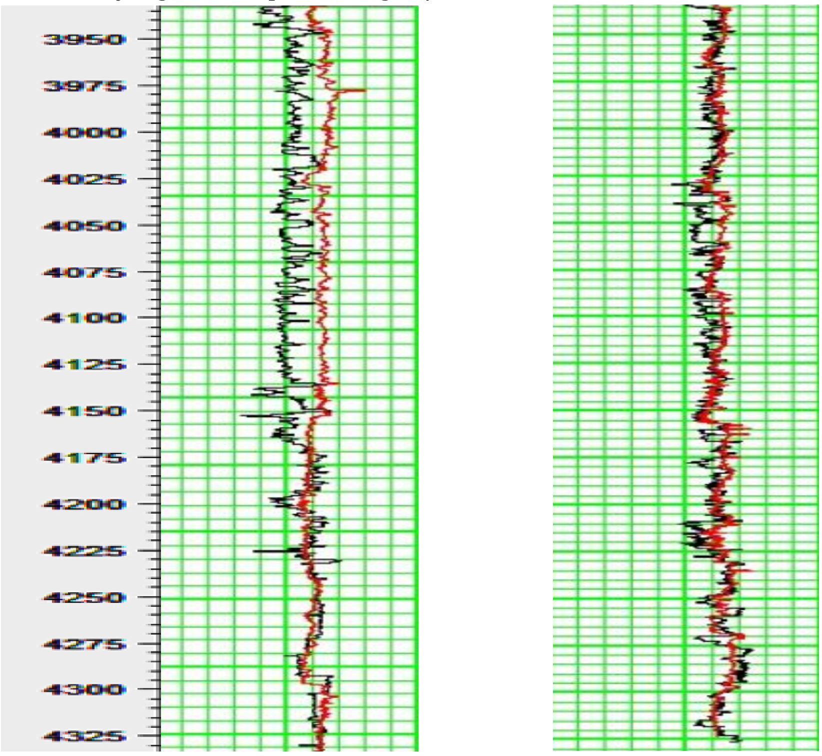


Figure 4: Overlay of Normal density log with a) estimated density from Gardner's relation with default parameters and b) using specific parameters for each rock type.

Different models were built using different Gardner's parameters and these models were used to infer lithologies by cross-plotting them with P-wave velocity. It is found that although the default Gardner's parameters of a=0.23 and m=0.25 are fairly adequate for lithology discrimination, the best discrimination was achieved when different values of a and m are used for different lithologies. This differentiation was noticed in both the overlay of synthetic density values and the density log as well as in the P-wave-density cross-plots. Resistivity log is added for knowing fluid bearing zones. The resistivity reading in sandy intervals shows the type of fluid present in that part of the formation

Figure 4 shows the estimated density log using Gardner's relation with different coefficients. Using Gardner's default parameters (4a) gives a poor fit in the shale section but improves significantly within the sand (>4100m). The best density log is estimated using specific Gardner's parameters for different rock types especially within the shale unit (Fig2, 3075-4050m) honoring the sharp decrease in density and other fluctuations.

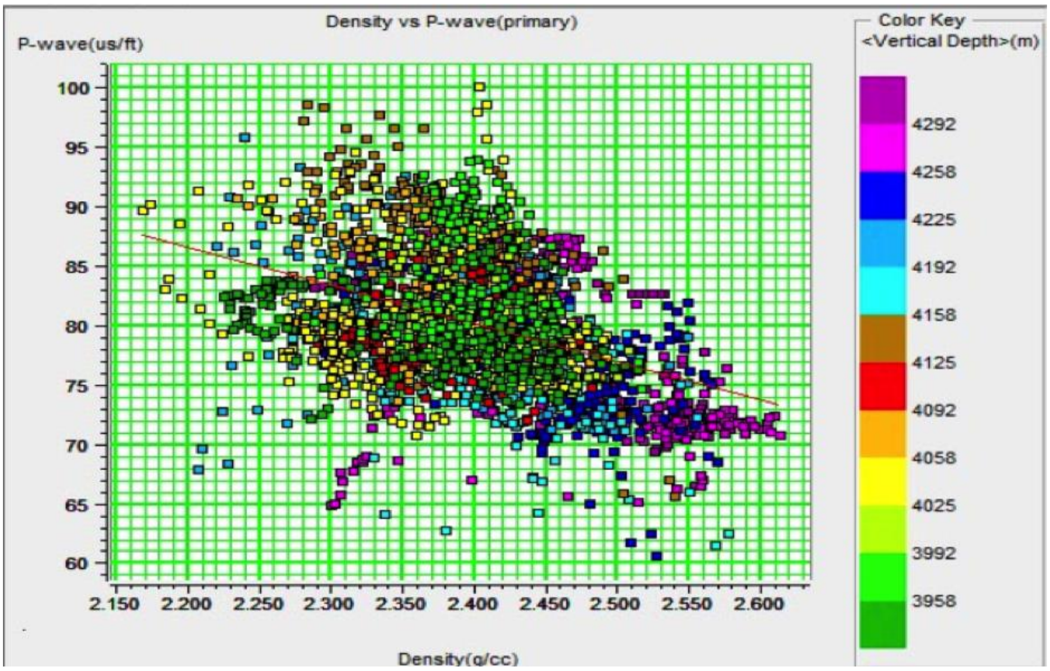


Figure 5: Density-P-wave cross-plot using Gardner's default parameters for well REGO 11

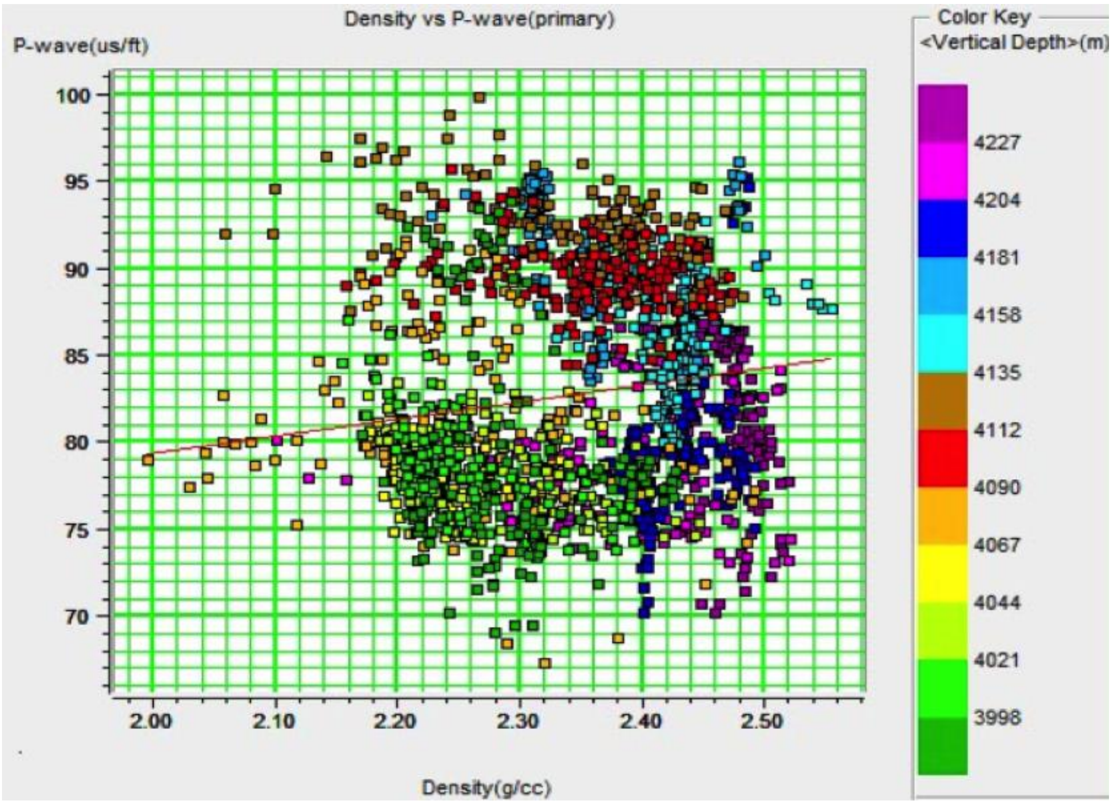


Figure 6: Density-P-wave cross-plot using specific parameters for Shale and Sand in Gardner's equation

Figure 5 shows a cross-plot of computed density against P-wave from the REGO 10 well. Velocity is in ms^{-1} while density is in gcm^{-3}. Notice that the points are not clearly differentiated in any part of the graph. Figure 6 shows the same cross-plot as Figure 5 but using specific values of *a* and *m* in computing the density from Gardner's relation. The lithologies are clearly differentiated in this case with the shale zone represented by the lighter colors (yellow and green) with density values ranging from 2.3-2.45 gcm^{-3}at 3998-4100m. The sand zone is represented by the darker colors (blue and red) with density values ranging from 2.4-2.5gcm^{-3}at depth > 4100m.

Conclusion

Gardner's equation is an important relation in estimation of density from both Vp and Vs seismic data. Although the default parameters of ***a=0.31*** and ***m=0.25*** are good for this relation, it is found that using specific values for ***a*** and ***m*** for different lithologies greatly improves the accuracy in the relation hence its use in lithology discrimination. Using a local fit for sands and shales, the values of **a** and **m** are found to be **0.52** and **0.20** for shales and **0.22** and **0.29** for sands. This indicates that the use of Gardner's relation to estimate density can go a long way in saving both time and resources in wells that the density was poorly logged or not logged at all.
In order to use density-velocity relations for lithology discrimination, it is recommended to evaluate the relations between the different logs and properties to estimate parameters from a local fit to the data. The Garner's default parameters can be adequate to generate initial density models, however, if these models are to be used for lithology discrimination, it is necessary to use specific parameters for each rock type in order to obtain more accurate results.

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