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POROSITY ESTIMATION USING RHG APPROACH AND WELL LOG DATA FROM SOUTHERN NIGER DELTA, NIGERIA

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ABSTRACT

Raw well data from oil wells A_{11}, A_{22} and A_{33} in the southern parts of the Niger Delta (A_{XX} Field) were used for porosity estimation using the Raymer Hunt Gardner (RHG) technique. Using Microsoft Excel for analysis and computation of results, gamma ray log, sonic log with respect to depth were generated. The results of these curves were used to estimate porosity. The major outcomes resulting from this porosity estimation revealed that porosity ranges from 22.0% to 41.0%, 25.0% to 37.0% and 16.0% to 38.0% for wells A_{11}, A_{22} and A_{33} respectively, with average values of about 33.5% for well A_{11}, 30.1% for well A_{22} and 27.1% for well A_{33}. Therefore, the average porosity obtained gives 30.2% in the A_{XX} field. The result of this estimation belongs to the excellent class of porosity estimation. It shows that the available pore spaces in the oil reservoir zone are adequate for migration, that is, it can store and transmit fluid. These results show that an increase in sonic gives rise to an increase in porosity irrespective of the lithology.

KEYWORDS: Well-log, RHG, Porosity, Gamma ray, sonic, A_{XX} Field.

INTRODUCTION

The estimation of porosity from well log data is an important task in the petroleum industry, as it offers valuable evidence concerning the capacity of reservoir rock to store and transmit fluids. Some reservoirs have porosity in the range of 5-45% with the majority falling between 10-20% (Egeh *et al*., 2001). Porosity is avital parameter for calculating the potential volume of hydrocarbons (Akankpo *et al*., 2015). It denotes the void spaces within a rock formation. Porosity fields can also be used to predict abnormal pressure areas during oil-well drilling (Uko *et al*., 2013; Udo *et al*., 2015: Atat *et al.*, 2012). The volume of the formation containing hydrocarbon is needed to estimate the total reserve and know if the accumulation is commercial.

Researchers such as Kirkham (2022), has worked on the Estimation of Porosity Using Mechanical Specific Energy (MSE) approach; Doveton (2014), estimated porosity based on measurements made from petrophysical logs considering the ratio of the volume of void space to the bulk volume of the rock; Kassab and Weller (2011), evaluates various well-known models and formulas for porosity estimation from compressional wave velocity; Sharifi *et a*l. (2023), have used a novel approach for fracture porosity estimation of carbonate reservoirs were they developed a fracture porosity estimation method using empirical and analytical solutions based on the wireline data considering stress conditions. De Abreu and Carrasquilla (2016), considered the porosities derived from density and neutron logs.

The main objective of this research is to estimate porosity which would offer valuable evidence concerning the capacity of reservoir rock of A_{XX} field on the storage and transmission of fluids. One commonly used method for porosity estimation is the Raymer Hunt Gardner (RHG) approach. The RHG field observation method is an empirical relationship that relates the porosity of a formation to the measured values of well log data. To estimate porosity, the values obtained from each log are averaged together to calculate an overall porosity value using the Raymer Hunt Gardner (RHG) equation. This information is crucial for reservoir characterization, hydrocarbon volume calculation, and overall reservoir evaluation. RHG technique is adopted for this finding as it has been shown to be adequate by other researchers for the estimation of porosity. Variation in fluid content within subsurface formations and diagenetic processes, such as compaction, cementation, and dissolution, can significantly impact the porosity of sedimentary rocks making it challenging to accurately estimate porosity (Atat *et al.*, 2022).

Location and Geology of the Study Area

The Niger delta (Figure 1) is located within latitude 3^0N and 6^0N; longitudes 5^0E and 8^0E (Akpabio *et al.*, 2023; Umoren *et al*., 2019; Reijers *et al.*, 1996). The southern Niger Delta, Nigeria is in the continental margin of West Africa, on the Gulf of Guinea. It extends from the coastal city of Port Harcourt to the city of Calabar, and it covers an area of about 9,000 square kilometers. Initially, the southern Niger delta was limited to the geographical area occupied mainly by the minorities of southern Nigerians but today, the region has become synonymous with the oil producing states (Usen, 2003).

The Niger Delta Province contains only one identified petroleum system (Kulke, 1995; Ekweozor and Daukoru, 1994). This system is referred to as the Tertiary Niger Delta (Akata –Agbada) Petroleum System (Atat and Umoren, 2016). Petroleum occurs throughout the Agbada formation of the Niger Delta (Udo *et al*., 2017). As stated by Atat and Umoren (2016), the Niger Delta is the youngest sedimentary basin in the Benue Trough system. The region experiences wet and dry seasons; average rain in a month during the wet season is about 135 mm and falls to 65 mm during dry season (Atat *et al*., 2020a; George *et al*., 2017; Atat *et al*., 2012; George *et al*., 2010). Groundwater is tapped from the top of the stratigraphic sequence (George *et al*., 2017). The volume of sediment is nearly 500000km^3 (Atat *et al.*, 2020b; Umoren *et al*., 2020; Atat *et al*., 2020c; Hospers, 1965, Akpabio and Ojo, 2018).

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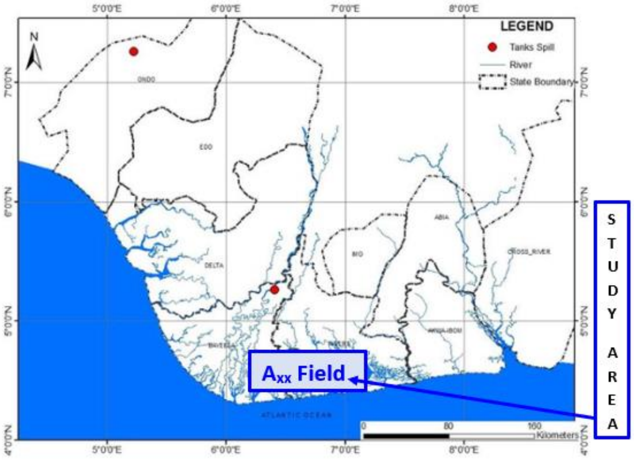

Figure 1: Map showing the location of study (Endoro, 2017).

THEORETICAL BASIS

Porosity is defined as the ratio of the volume of void space to the total volume of the material or rock. The symbol for porosity is the Greek letter, phi Φ. It is mathematically expressed in Equation 1.

$$\Phi = \frac{pore\ volume}{volume\ of\ formation} \tag{1}$$

Porosity of a formation is important in evaluation of fluid content, potentiality of fluid flow and recaptures amounts in a pool (Prasad, 2003). The criteria for classifying porosity include porosity values less than 5% is negligible, between 5% to 10% is poor, greater than 10% but less than 15% is fair, about 15% to 25% is good, from 25% to less than 30% is very good and porosity values greater than 30% is excellent (Land, 1968; Atat *et al*., 2022).

The volumetric concentration of pore space can be determined using Equation 2.

$$\Phi = \frac{Pore\ Volume}{Bulk\ Volume} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \tag{2}$$

Φ is the porosity
ρ_{ma} is grain matrix density
ρ_f is fluid density
ρ_b is the bulk density of the formation (Serra, 1984).
The assumed fluid density is usually between 1.0 and 1.1. If gas is present, the actual fluid density will be < 1.0 and the calculated porosity will be really high (NExT PERF, 1999). Other factors such as age of sediment, maximum depth of burial, formation temperature, abnormal pore pressure, hydrocarbon saturation, compaction, anthogenesis of minerals and leaching also influence porosity (Akankpo *et al*., 2015). Porosity can be derived from Sonic log and may be expressed mathematically as seen in Equation 3.

$$\Phi_{sonic} = \frac{t_{log} - t_{ma}}{t_f - t_{ma}} \tag{3}$$

Φ_{sonic} is the sonic derived porosity
t_{log} is sonic log reading in μsec/ft
t_{ma} is the matrix travel time in μsec/ft
t_f is the fluid travel time in μsec/ft (about 189 for freshwater mud system) (Wyllie *et* al., 1956).

The Raymer Hunt Gardner (RHG) approach is a widely used well log-based method for porosity estimation. The RHG approach utilizes the combination of different well logs, such as sonic and gamma ray logs to estimate porosity. The approach involves the calibration of empirical equations derived from core analysis data, relating log measurements to porosity. The RHG equation incorporates various log responses, considering the rock matrix, fluid saturation and porosity. Porosity estimation using the Raymer Hunt Gardner approach can be calculated using Equation 4 (Atat *et al*., 2022).

$$\Phi = C_r\left(\frac{t - t_{ma}}{t}\right) \tag{4}$$

Φ is the Raymer Hunt Gardner estimated porosity
t is the reading on the sonic log
t_{ma} is the interval transit time of matrix material
C_r is the coefficient of the Raymer Hunt Gardner equation, ranging from 0.625 and 0.700 depending upon local conditions. The most widely accepted value is 0.670 (Atat *et al*., 2022). The sonic log measures the travel time of a compressional wave through the rock formation, and the porosity is estimated by comparing the measured sonic velocity with the velocity of the matrix rock.

MATERIALS AND METHOD

Materials

Data obtained from the onshore Niger Delta oilfield include: depth, sonic, density and Gamma Ray. The software used for the analysis, processing and computation is the Microsoft Excel.

Method

The data used for this study were from three wells in the A_{XX} Field of the southern Niger Delta, Nigeria. The wells are A_{11}, A_{22} and A_{33}. The different stages of workflow (Figure 2) employed include: Data loading, conditioning, editing, and processing, lithology identification and estimation of porosity using Raymer Hunt Gardner Technique (Equation 4). The lithology was identified by defining the shale base line to be 75 API (American Petroleum Index), separating from sand formation across the entire A_{XX} Field. The depths with shale-sand-shale lithology were marked and porosity estimated.

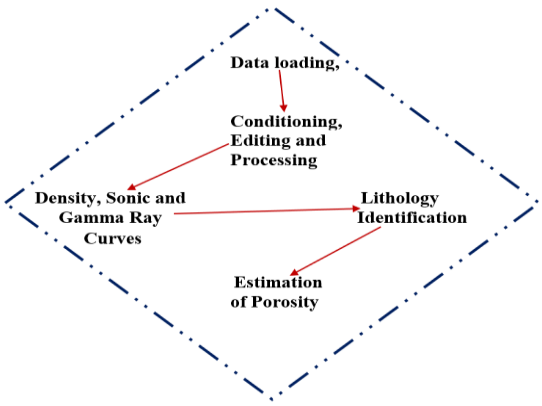

Figure 2: Workflow of the study

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RESULT AND DISCUSSION

Three wells of A_{XX} Fields were studied and the results are illustrated graphically in Figures 3 to 8. Suites of log were generated as presented in Figures 3, 5 and 9 which are results of discrimination. Porosity estimates using Equation 4, yielded Figures 4, 6 and 8 respectively for wells A_{11}, A_{22} and A_{33}.

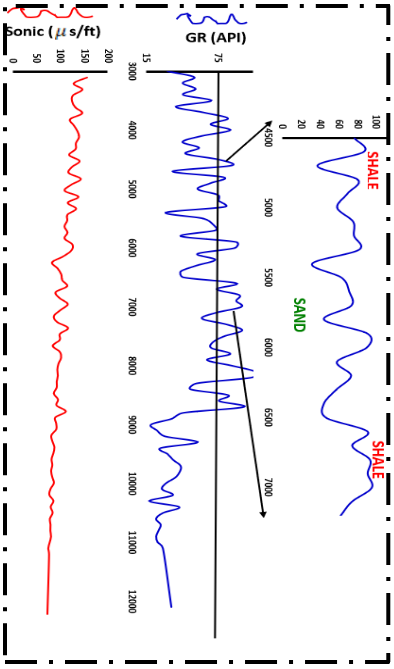

Figure 3: Sonic (in red) and Gamma Ray (in blue) Curves with respect to Depth indicating the Sandstones and Shales Lithologies of Well A_{11}

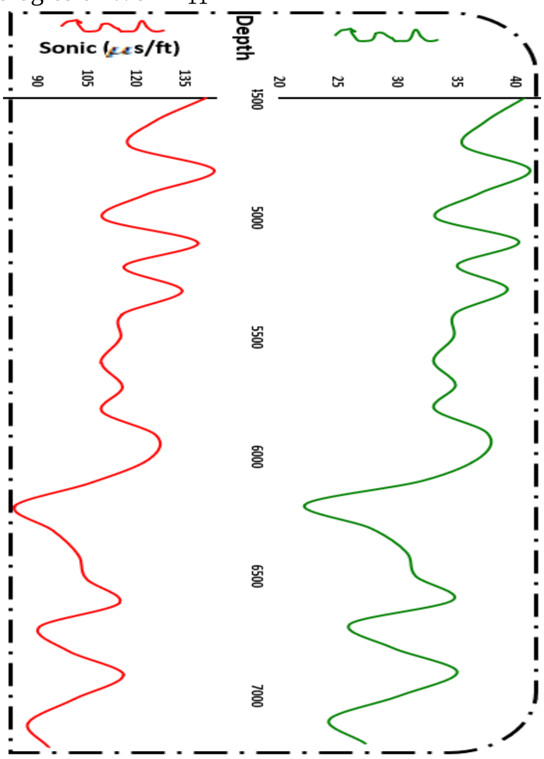

Figure 4: Porosity (in green) Estimates from Well A_{11}

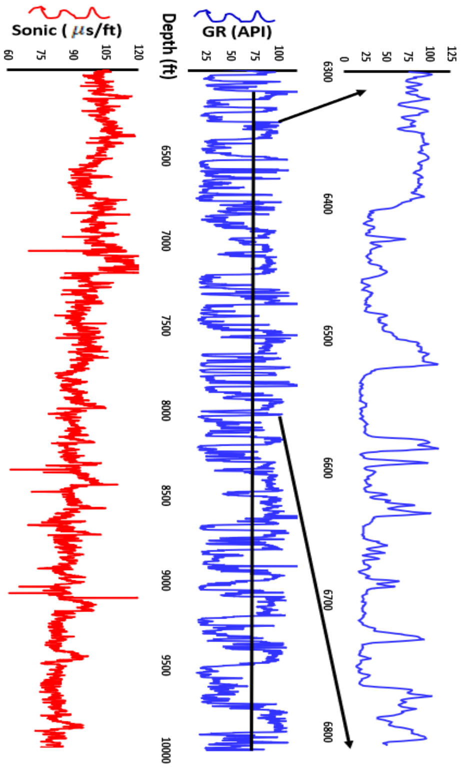

Figure 5: Sonic (in red) and Gamma Ray (in blue) Curves with respect to Depth indicating the Sandstones and Shales Lithologies of Well A_{22}

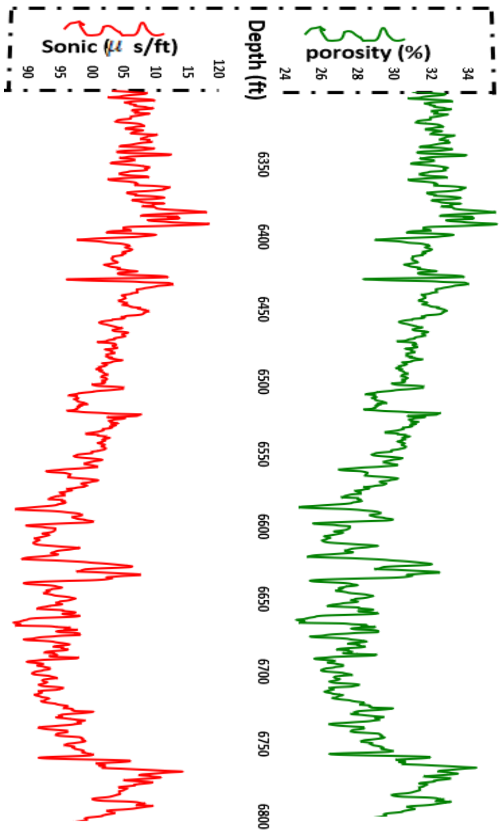

Figure 6: Porosity (in green) Estimates from Well A_{22}

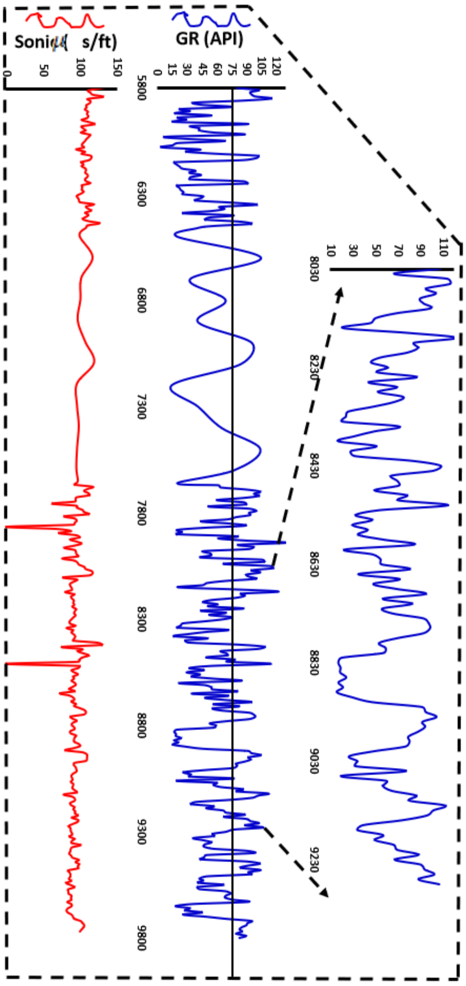

Figure 7: Sonic (in red) and Gamma Ray (in blue) Curves with respect to Depth indicating the Sandstones and Shales Lithologies of Well A_{33}

DISCUSSION

From the data obtained and processed, the porosity analysis for each well using the Raymer Hunt Gardner (RHG) equation gives better results. An investigation on porosity estimates using the Raymer Hunt Gardner (RHG) approach and well log data in sandstones lithology and shale lithology was performed. The Field location studied is A_{XX} in the Southern part of Niger Delta, Nigeria.

The raw data were analyzed to create suites of logs (Figures 3, 5 and 7) which include sonic log (red) and gamma ray log (blue) with respect to depth. Gamma ray log was used to identify the lithologies (sandstone and shale) since we need this information to identify the reservoir for each well. The dominant lithology at the top of A_{XX} reservoir is the shale with API value greater than 75; the dominant lithology in the reservoir is sandstone with API value less than 75. The information obtained from gamma ray log led to the appropriate wells reservoir thicknesses examined such as 2700ft (823m), 510ft (156m) and 1250 (381m) for wells A_{11}, A_{22} and A_{33} respectively. The corresponding depth and sonic log obtained were adequate for the porosity estimates (green) in the A_{XX} Field (Figures 4, 6 and 8).

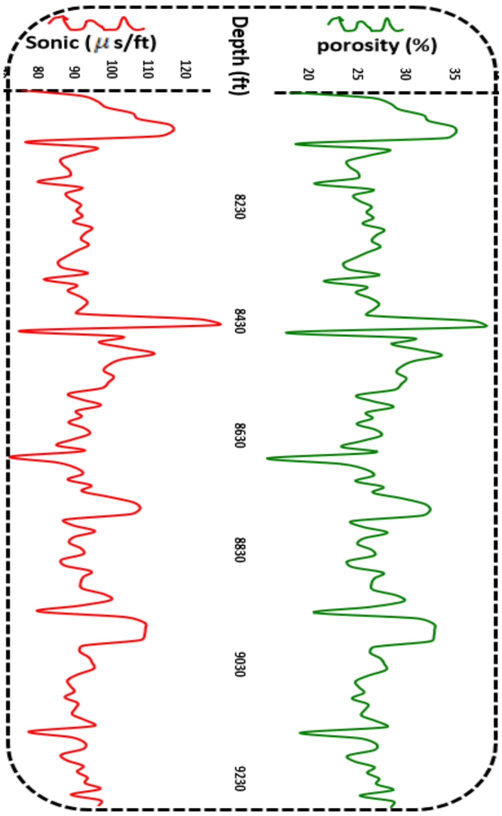

Figure 8: Porosity (in green) Estimates from Well A_{33}

Equation 4 was employed in Microsoft Excel for mathematical analysis and porosity information of the formation was determined. The results of porosity estimate for wells A_{11}, A_{22} and A_{33} have been presented. The results show that porosity ranges from 22.0% to 41.0%, 25.0% to 37.0% and 16.0% to 38.0% for wells A_{11}, A_{22} and A_{33} respectively. These result in the average values of about 33.5% for well A_{11}, 30.1% for well A_{22} and 27.1% for well A_{33}. The average porosity obtained for A_{XX} Field is 30.2%. Increase in sonic leads to an increase in porosity irrespective of the lithology (Figures 4, 6 and 8).

Porosity values less than 5% are negligible, between 5% to 10% is poor, greater than 10% but less than 15% is fair, about 15% to 25% is good, from 25% to less than 30% is very good and porosity values from 30% above is excellent. This implies that porosity estimation using Raymer Hunt Gardner Equation and well log data in the A_{XX} Field gives an excellent result. Therefore, the volumetric concentration of hydrocarbon or ability to store and transmit fluid is very high (or adequate). The porosity here is total which could yield effective porosity with respect to the volume of shale.

CONCLUSION

Porosity estimation is essential for assessing the potential volume of hydrocarbon it may contain as it evaluates the pore spaces in a formation. The estimates from the Raymer Hunt Gardner equation show that an increase in sonic leads to an increase in porosity of the formation. The results show that the average porosity is about 33.5% for well A_{11}, 30.1% for well A_{22} and 27.1% for well A_{33}. These result in the average porosity of about 30.2% for the A_{XX} Field. These wells are highly porous and well suited for storage and transmission of hydrocarbons as this investigation reveals an excellent class of porosity in the formation.

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